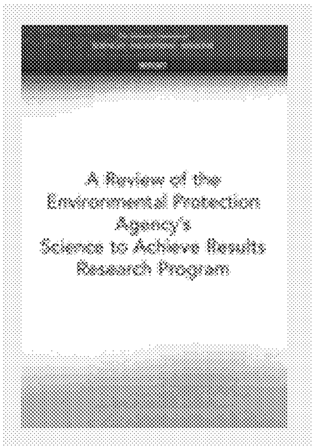

A Review of the Environmental Protection Agency's Science to Achieve Results Research Program

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A Review of the Environmental Protection Agency's Science to Achieve Results Research Program

Committee on the Review of Environmental Protection Agency's Science to Achieve Results' Research Grants Program

Board on Environmental Studies and Toxicology
Division on Earth and Life Studies

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Preface

Environmental research plays a crucial role in protecting human health and the environment. The US Environmental Protection Agency (EPA) has been supporting environmental research in academic and nonprofit institutions through a program known as Science to Achieve Results, or STAR. STAR aims to support research projects that are chosen through a competitive process of independent peer review that focuses on research in environmental and human health problems. STAR research is intended to provide the underlying scientific and engineering knowledge needed to address environmental and human health issues and to improve decision-making, problem detection, and problem-solving.

The EPA asked the National Academies of Sciences, Engineering, and Medicine (NASEM) to conduct an independent assessment of the STAR program. In response, the NASEM established the Committee on the Review of EPA's Science to Achieve Results. In this report, the committee analyzes information provided by EPA, and other sources to assess the program's scientific merit, benefits to the public, and overall contributions in the context of other relevant research. The committee also compares some of the procedural aspects of the STAR program with those of other extramural research programs.

The committee's report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise. The purposes of the independent review are to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following for their review of the report: Craig Benson, University of Virginia, Charlottesville, Virginia; Nicole Deziel, Yale University, New Haven, Connecticut; Gretchen Jordan, 360 Innovation, Pacific Grove, California; Julia Melkers, Georgia Institute of Technology, Atlanta, Georgia; D. Werner North, NorthWorks, San Francisco, California; Donald Pfaff, The Rockefeller University, New York, New York; Patrick Ryan, Cincinnati Children's Hospital, Cincinnati, Ohio; Jerald Schnoor, The University of Iowa, Iowa City, Iowa; and Kathleen Weathers, Cary Institute of Ecosystem Studies, Millbrook, New York.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of the report was overseen by Edwin Clark, Clean Sites Environmental Services, Inc. and Dave Dzombak, Carnegie Mellon University, they were responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests entirely with the committee and the institution.

The committee gratefully acknowledges the following for making presentations to it: Tina Bahadori, Thomas Burke, Daniel Costa, James Johnson, Michael Slimak, John Vandenberg, and, Suzanne van Drunick, EPA; Steven Hamburg, Environmental Defense Fund; Daniel Greenbaum, Health Effects Institute; Christina Drew, National Institute of Environmental Health Sciences; Marina Volkov, National Institutes of Health; Mary Ann Feldman and Thomas Torgenson, National Science Foundation; and Paul Anastas, Yale University. We are also grateful to the many EPA National Center for Environmental Research staff members who invested extensive time and effort in responding to all the committee's requests for information.

The committee is grateful in addition for the assistance of the National Academies staff in preparing this report: Elizabeth Boyle, project director; James Reisa (until January 3, 2017) and Teresa Fryberger (after January 3, 2017), directors of the Board on Environmental Studies and Toxicology; Raymond Wassel, scholar; and Orin Luke, senior program assistant. Norman Grossblatt served as the report editor.

Finally, I thank the members of the committee for their dedicated efforts throughout the development of this report.

Mark Utell
Chair, Committee to Review EPA's Science
to Achieve Results Research Grants Program

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Summary

Environmental research has driven landmark improvements that led to the protection of human and ecosystem health. Recognizing the value of knowledge generated by environmental research and the ingenuity within academic and nonprofit institutions, the US Environmental Protection Agency (EPA) created a program known as Science to Achieve Results, or STAR, in 1995. STAR is EPA's primary competitive extramural grants program. This report shows that through STAR, EPA has created a vehicle that fosters collaboration and knowledge-sharing, which have produced research that has supported interventions that may reduce the cost of regulations, protect public health, and save lives.

STAR is managed by EPA's National Center for Environmental Research and integrated into the Officer of Research and Development's (ORD's) overall research program through planning and coordination with EPA's laboratories, offices, and centers. STAR research support consists of three main types: grants to individual investigators; larger multidisciplinary center grants, usually to groups of institutions; and a recently discontinued fellowship program, which supported master's and doctoral students.

In 2003, a National Research Council committee reviewed STAR and strongly endorsed it as an integral part of EPA's research program. That committee believed that STAR provided the agency access to external and independent information, analyses, and perspectives. However, the STAR program was too young to fully evaluate its effects.

Since that review, there have been changes in the program. For example, funding has fluctuated, with a peak of around $138 million (2016 dollars) in 2001 and 2002, which represented 18% of ORD's total budget; a median of $75 million (2016 dollars) in 2007, which represented 12% of ORD's total budget; and a minimum of $39 million in 2016, which represented 8% of ORD's total budget. Funding for the STAR fellowship program was eliminated for FY2016 to centralize graduate fellowships in the National Science Foundation (NSF).

THE COMMITTEE'S REVIEW

EPA asked the National Academies of Sciences, Engineering, and Medicine to conduct an independent assessment of the STAR program. The committee established in response to the request was charged with assessing the program's scientific merit, public benefits, and overall contributions in the context of other relevant research and with recommending ways to enhance those aspects of the program.

The committee was also asked to consider the conclusions and recommendations of the prior National Research Council review of the STAR program (2003), the STAR program's research priorities in light of the nation's environmental challenges, and the effects of recent STAR funding trends on obtaining scientific information needed to protect public health and the environment.[1] The committee's approach is detailed in Box S-1.

[1]According to the president's budget blueprint submitted to Congress on March 16, 2017, "ORD would prioritize activities that support decision-making related to core environmental statutory requirements, as opposed to extramural activities, such as providing STAR grants."

A Review of The Environmental Protection Agency's Science to Achieve Results Research Program

BOX S-1 The Committee's Approach to the Evaluation

- To assess whether STAR procedures sponsor research of high **scientific merit** the committee compared STAR's operating procedures with those of other extramural research programs that fund research in similar fields and read all STAR requests for applications released in 2003-2015 (see Chapter 2).
- To assess the program's **public benefits**, the committee created a logic model and then evaluated the program at various points along the model (see Chapter 3).
- To assess STAR's **research priorities** in light of the nation's environmental challenges, the committee considered whether STAR research supports scientific fields that are important for addressing the challenges. It also considered how STAR has been used to address the nation's changing environmental priorities (see Chapter 4).

SCIENTIFIC MERIT

The committee compared STAR's procedures for priority setting, soliciting, awarding, and administering grants, with those of research programs of the California Air Resources Board, the Health Effects Institute, the National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science, the US Department of Agriculture's National Institute of Food and Agriculture, the NSF Division of Earth Sciences, and the National Institute of Environmental Health Sciences (NIEHS) Division of Extramural Research and Training (Chapter 2).

The committee found no major deficiencies in STAR's procedures. STAR priority-setting procedures are integrated within four of ORD's national programs; this allows STAR to be flexible in light of the nation's changing research priorities and avoids duplication of EPA's internal research. STAR was the only research program included in this comparison that allowed neither submission of research topic ideas by the general public nor unsolicited proposals; this characteristic may limit the creativity of the program and merits consideration.

Having reviewed the RFAs, the committee noted that the STAR program's RFAs are generally of good quality and address a wide variety of topics. STAR has strong peer-review procedures, and it is a highly competitive program, with a median grant application award rate of 16% in 2003-2014. After peer review, EPA staff review grant applications for relevance to the intent of the RFA; it is unclear whether investigators receive comments on their applications' relevance reviews.

- **Finding 1. EPA has high-quality procedures for priority-setting that allow STAR to be integrated within EPA's research program.**
    - ➢ **Recommendation 1. EPA should continue to use its procedures for strategic planning and for setting priorities for STAR research. However, EPA should consider developing a mechanism to allow for public input to the STAR research agenda or the submission of unsolicited proposals.**
- **Finding 2: STAR's procedures to develop funding announcements and award grants ensure that the program sponsors research of high scientific merit.**
    - ➢ **Recommendation 2. The STAR program should maintain the procedures that it has in place. However, it should provide comments to applicants whose applications were not awarded because of lack of relevance so that they can improve their ability to prepare future grant proposals.**

PUBLIC BENEFITS

The STAR program is productive. In 2003-2015, STAR awarded 541 individual-investigator grants, 53 center grants, and 800 fellowships (Chapter 1). In October 2002-April 2017, there were 5,760 STAR journal publications (Chapter 3). The committee found that results of STAR-funded research are used by many different kinds of organizations, for example, in federal, state, and local government documents; in international guidelines; and in other documents of academic or nonprofit organizations, such as National Research Council reports and American Public Health Association guidelines. In 2012, at least 105 STAR-funded papers were cited in those types of documents. The committee found that those outputs and outcomes have led to numerous public benefits (Chapter 3). Some examples are the development of an environmental-science workforce, the development of human-resources and research infrastructure across the nation, a potential reduction in the costs of compliance with environmental regulation, provision of the scientific basis of decisions required to protect public health and the environment, and the study of methods for improving environmental management.

Support of Public-Health Decisions

STAR research has supported numerous public-health decisions. The STAR program implemented several large initiatives that address the human health effects of air pollution, such as the Particulate Matter Centers, the Clean Air Research Centers, and the Air, Climate, and Energy Centers. Studies supported by the centers showed that increased air-pollution exposure leads to a decrease in life expectancy; they include a followup of the Harvard Six Cities Study published in 2006 and a large ecologic study of $PM_{2.5}$ exposure and mortality in 51 US cities published in 2009. Those findings supported earlier research and led to the development of a more scientifically justified $PM_{2.5}$ national ambient air quality standard (NAAQS) which may have saved lives and reduced healthcare costs nationwide.

Another effective initiative is the Children's Environmental Health and Disease Prevention Research Centers, which are supported by STAR center grants. The grants are funded in partnership with the National Institute of Environmental Health Sciences (NIEHS) and aim to evaluate the effects of environmental exposures on child health and development. In 2016, a research project partially supported by a STAR grant found that infants could be exposed to arsenic through rice cereal, and this led the Food and Drug Administration to propose regulations to protect infant health. Another example is the discovery by the University of Washington Children's Center that farmworker children had increased exposure to the pesticide ingredient azinphos-methyl which is a neurotoxin; this finding informed EPA's decision to phase out the use of the azinphos-methyl.

Examples of STAR research to improve environmental management include experiments in market-based incentives to lower emissions and studies that evaluated the potential reduction in the cost of pollution abatement and auctions in which landowners and land sellers compete to obtain part of a fixed budget allocated by the regulator to subsidize pollution abatement.

Potentially Reducing the Cost of Compliance with Regulation

STAR research has led to potential reductions in the cost of complying with environmental regulations. The reductions would benefit regulated industries and states and localities that need to comply with environmental regulations. An example of STAR research that may benefit industry is the development of a tissue-based method for evaluating the thyroid effects of chemical exposures. The method may substantially reduce the costs of chemical testing compared with animal-based approaches. STAR research has also expanded the capability of climate and air-pollution models, and this may reduce the costs of compliance with NAAQSs. Another research project supported by STAR discovered a cost-effective way to remove nitrate from drinking water.

Workforce Development

In 2003-2015, STAR awarded 800 graduate fellowships. Many former STAR fellows continued in environmental and environmental health sciences careers. Among former STAR fellows who reported on their careers' trajectory to EPA, 34% were in postdoctoral positions; 21% in teaching positions; 16% in research; 12% in the federal government; 5% in consulting firms; 4% in state, local, or tribal government; 4% in private industry; and 3% in nonprofits. The committee also found evidence that STAR fellows produced high-quality science; for example, a search for frequently cited STAR publications in Google Scholar found that about one-fourth were at least partially supported by a STAR fellowship.

Infrastructure Development

In FY 2014, the STAR program had grantees or fellows in all but two states (Vermont and South Dakota) (Figure S-1). Engagement with EPA in institutions throughout the United States has created communities of scientists and engineers working in the human health and environmental sciences that might not have existed without support from STAR grants. In addition, research grants help to improve facilities for data collection and analysis within the supported grantees' institutions.

Tracking of Public Benefits of STAR Research

Tracking of the public benefits of research is difficult; all research programs struggle with tracking public benefits and attributing them to single research projects. One issue that made it difficult for STAR is that the EPA grantee project-results Web site was not up to date. There were many examples of grants long completed or at least in operation for a number of years on which annual or final reports were unavailable (see Chapter 2).

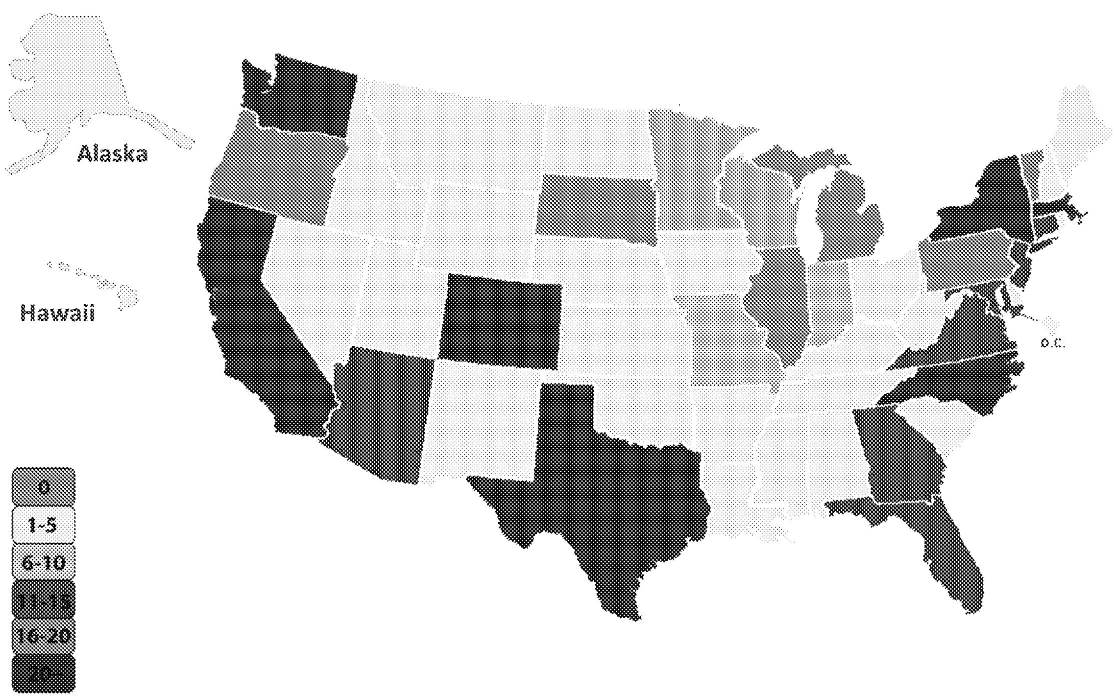

FIGURE S-1 Geographic distribution of STAR grants, centers, and fellowships in FY 2014. Yellow indicates 1-5, green 6-10, purple 11-15, blue 16-20, and red over 20 active grantees in a state in 2014. In FY 2014, there were a total of 506 active STAR individual-researcher grants, centers, and fellowships.

STAR has made efforts to translate research to a broader audience and synthesize information on a given RFA topic by having investigators from different grantee institutions collaborate on summary reports, but the efforts have been inconsistent (see Chapter 3). The overall benefits of the science could be strengthened if grantees consistently created synthesis reports and held more public webinars to discuss research.

The committee acknowledges that many other research programs struggle with such challenges (see Chapter 3). Evaluations like the present one would be improved if there were more robust electronic databases that could be easily searched to detect linkages between grants, fellowships, and public benefits. There have been advances throughout the federal government to mine existing data in reports, academic literature, administrative records, and so forth, to identify intermediate outcomes more effectively, to link federally funded projects to long-term effects, and to track career outcomes of graduate students supported by fellowships or graduate research assistantships. The National Institutes of Health (NIH), for example, has created the High Impacts Tracking System. The system loads progress reports and program officers' notes about grants into a searchable system and allows structured tagging of outputs and effects. Another NIH example is RePARS, which permits automatic retrieval of sources of NIH funding of publications in any list, such as the bibliography of a National Academies report. Those efforts have recently been used to evaluate the National Toxicology Program's effects on a water-quality standard for hexavalent chromium in California. EPA could make strides in this regard by collaborating with other organizations that are linking public benefits to research.

EPA would benefit from working with other federal agencies that are advancing ways in which such benefits are communicated to the public. NIH has found that the links between research studies and benefits to human health are described best in stories or case studies that resonate with those outside the research community. EPA should consider reporting stories more prominently on its Web site and blogs. STAR should also consider requiring grantees to report the potential influence and public benefits of their awards as part of their final reports and even 5-10 years after their research has been completed.

The Fellowship Program

As discussed previously, the STAR fellowship program supported students who continued careers in environmental and environmental health sciences. The STAR fellowship program was distinctive in that it covered both environmental and environmental health research. The two other agencies that support predoctoral fellows will not fill this gap: NSF training programs do not cover environmental health effects, and NIH training programs are geared toward overall health sciences. In addition, it appears that the move to centralize graduate fellowships in NSF has led to a large reduction in the support of students interested in environmental research. In 2015, there were 168 NSF fellows in environmental sciences and ecologic research and 51 STAR fellows. In 2017, after the STAR fellowship program was canceled, there were 176 NSF fellows in environmental sciences and ecologic research; thus, there are indeed fewer fellowships in environmental and environmental health sciences. The need for federally supported fellowship programs in the environmental arena is important in that the United States is projected to have considerable human-resources needs in the science and engineering policy fields.

- **Finding 3. The STAR program has generated research that has many public benefits. However, these public benefits are not consistently tracked and synthesized.**
  - ➢ **Recommendation 3. The STAR program should partner with other federal agency efforts to improve communication of the benefits of its research to the public. In addition, EPA should update the grantee project results Web site.**
- **Finding 4. The STAR fellowship program was critical for training future generations of scientists who pursue environmental careers.**
  - ➢ **Recommendation 4. The STAR fellowship program should be restored to EPA given the continued and growing need for scientists in environmental research and management.**

A Review of The Environmental Protection Agency's Science to Achieve Results Research Program

ADDRESSING EPA'S PRIORITY SCIENTIFIC QUESTIONS

Does the STAR program contribute to fields that will help to improve human health and the environment? To answer that question, the committee first considered what scientific disciplines and fields of study are needed to produce knowledge and capacity to protect human health and the environment. It then considered how STAR has engaged the various disciplines, which range from basic sciences—such as the earth sciences, atmospheric sciences, life sciences, ecology, and toxicology—to applied domains, such as environmental engineering, sustainable energy, human exposure and health effects, and human behavioral studies. The committee categorized the RFAs released by STAR in 2003-2015 and the STAR research papers that it identified as having been cited more than 100 times in a Google Scholar search according to the fields of knowledge that will help to improve human health and the environment.

Through its assessment, the committee found that STAR supports work in almost every field identified that contributes to environmental knowledge and capacity. The most common fields identified were the atmospheric sciences, climate sciences, ecology, environmental economics, environmental engineering, human exposure and health effects, risk analysis, systems modeling and decision support, and innovative risk management. Many other federal research programs support scientific study in those fields. What distinguishes STAR from the other programs is not specifically the research topics that it supports but that its RFAs cover subjects that are important to EPA's mission and that it addresses knowledge gaps which will protect human health and the environment. Examples of how EPA has used STAR to address knowledge gaps or to respond strategically to emerging challenges are numerous (Chapter 4). The committee found that STAR has been called on to address human health and environmental concerns related to new technology, to address knowledge gaps identified in connection with environmental disasters, and to evaluate potential consequences of resource-conservation technologies. Some recent examples are the release of RFAs that cover the health effects of engineered nanoparticles, the environmental effects and mitigation of oil spills after the Deepwater Horizon incident, and human and ecologic effects associated with water reuse and conservation practice (Chapter 4 and Appendix C).

The ability of EPA to use STAR to strategically address knowledge gaps has weakened in recent years; STAR has not had the ability to release as many RFAs. In 2003, it released 12 individual-investigator grant RFAs and one center RFA. In 2013 and 2014, it released five individual-investigator RFAs and two center RFAs a year. In 2015, it released only one individual-investigator RFA. The change limits the number of topics in which the STAR program is investing.

- **Finding 5. STAR plays a distinctive role in the nation's overall environmental-research portfolio.**
  - ➢ **Recommendation 5. The committee recommends that EPA continue to use STAR to respond to the nation's emerging environmental challenges.**

CONCLUSIONS

Environmental research has led to technologic advances and to policies that have resulted in enormous improvements in human health and the environment. However, many persistent environmental challenges remain, and complex challenges with unknown effects on human health and the environment are emerging. For example, increased energy demands have led to advanced approaches to oil and gas extraction that have unknown environmental effects. Increasing urbanization has led to changes in land-use patterns, which may have adverse effects on the quality of air, land, and water and on human health. Agriculture and food production change as technology advances. Environmental research supplies the critical knowledge needed to address such challenges. The committee found that STAR has been integral to EPA's efforts to address evolving environmental research priorities and that these efforts have benefited the public. The committee recommends that EPA continue to use the STAR program to address our nation's evolving environmental research priorities.

1

Introduction

Environmental stressors have an enormous impact on human health. Almost one-fourth of the global burden of disease may be attributed to environmental factors (Cohen et al. 2017), so improving our nation's understanding of the effects of the environment on health and well-being is critical. Through environmental research, the health effects of lead in gasoline were discovered, and policies were then developed to prohibit its use as an additive (EPA 1997). Environmental research has identified susceptible groups within populations by distinguishing vulnerable life stages and genetic factors (Landrigan et al. 2002; EPA 2007). Environmental engineers have developed technologies to monitor and improve water quality in lakes and streams (Walsh et al. 2005), spurred improvements in energy-use efficiency (Boyd 2005), and encouraged reuse of waste (Witt 2003). Environmental epidemiologists have learned that environmental tobacco smoke is a human carcinogen (Sun et al. 2007). Environmental research has been the engine that has driven those landmark improvements and is necessary to protect future human and ecosystem health (NRC 2012)[1].

Environmental research can be both basic and applied and is conducted by government agencies, by the industrial sector, and in academic and other research organizations. In general, agencies with some regulatory authority—such as the US Department of Agriculture, the Centers for Disease Control and Prevention, the Food and Drug Administration, the Department of Energy, and the Environmental Protection Agency (EPA)—tend to conduct more applied research, whose objective is to gain knowledge or understanding necessary for determining how a recognized need may be met. Basic research, which is conducted to gain a more complete knowledge or understanding of the fundamental aspects of phenomena without specific applications aimed at processes or products in mind, tends to be conducted by nonregulatory agencies, such as the National Science Foundation (NSF) and the National Institutes of Health (NSF 2013).

EPA research is unique in that it covers applied research in both human health and the environment. Research is vital for understanding mechanisms for protecting human health and the environment and is thus crucial to EPA's mission, as numerous reports have stated emphatically (NRC 1997, 2000, 2008, 2012). EPA research is collaborative and cross-disciplinary and has been bolstered by strong ties to academic research institutions that represent many sectors of the scientific community (NRC 2012). One avenue used to encourage ties to other research institutions is EPA's extramural research program. EPA has had both intramural and extramural research programs since its creation. In the early days, the extramural program was managed by its laboratories and other technical facilities around the nation (NRC 2014). The managers of EPA's Office of Research and Development (ORD) laboratories controlled extensive extramural research resources. For example, the budget in 1981 for EPA extramural research was roughly $250 million (EPA 1980), equivalent to $655 million in 2016 dollars (BLS 2016). The extramural funds were so considerable in the early years of EPA because the growing US environmental agenda placed a heavy burden on ORD for research results. ORD struggled to respond, and laboratory managers relied heavily on contracts and cooperative agreements to meet its needs. The complex funding arrangements

[1]Publications after July 2015 are no longer referred to as National Research Council (NRC) due to the name change to the National Academies of Sciences, Engineering, and Medicine.

created problems related to the management of research and to ensuring that the work was responsive to the needs of the program offices (Johnson 1996; NRC 2003). There also was a general perception that laboratory managers had substantial local autonomy and control over funding decisions. There was little coherent or transparent policy for external peer review of proposals as commonly used in the scientific community (Johnson 1996; NRC 2003).

To respond to concerns about the complexity of the extramural program, Robert Huggett, assistant administrator of EPA for ORD, reorganized ORD and initiated the Science to Achieve Results (STAR) program in 1995. He reallocated $57 million in funds from other ORD-sponsored research efforts, primarily the "exploratory research" program (NRC 2003). The new STAR program was assigned to one of the ORD's research centers, the National Center for Environmental Research and Quality Assurance, now the National Center for Environmental Research (NCER), which addressed the transparency concerns related to the previous program by creating standard procedures for peer review and awarding of grants. The program was designed to meet the long-term research needs of the nation through extramurally funded projects centers and fellowships (NRC 2003).

STAR is still managed by NCER. NCER's portfolio now consists of such programs as Small Business Innovation Research contracts and other support initiatives, such as the undergraduate Greater Research Opportunities (GRO) fellowships; People, Prosperity and the Planet awards; other congressionally directed research grants and centers; and STAR. STAR is a competitive peer-reviewed research grants program that supports environmental research in academic and other nonprofit organizations. Until 2016, STAR provided graduate fellowships for master's and PhD students and funding for research pertaining to human health and the environment. In 2015, it was decided that science, technology, engineering, and mathematics (STEM) programs and activities throughout the federal government should be consolidated in the 2016 budget; the resources for the STAR fellowships were redirected to NSF (Johnson 2016; OSTP 2015).

FUNDING OF THE SCIENCE TO ACHIEVE RESULTS PROGRAM

Funding for the STAR program has fluctuated, with a peak of around $138 million (2016 dollars) in 2001 and 2002, a median of $75 million (2016 dollars), and a minimum of $39 million in 2016 (see Figure 1-1). In 2000, the STAR program accounted for 17% of the total ORD budget (Figure 1-2). In the intervening years, the total budget for ORD fluctuated between $835 million (2016 dollars) in 2003 and $513 million in 2016, and the STAR program now accounts for about 8% of the total ORD budget (Johnson 2016).

THE COMPONENTS OF THE SCIENCE TO ACHIEVE RESULTS PROGRAM

The components of STAR have also evolved. Exploratory grants awarded in response to general solicitations were an early part of the program, but there has been a shift toward more topically focused research questions embodied in requests for applications (RFAs) (NRC 2003). Now there are focused grants to individual investigators and larger center grants, and until 2016 there was a graduate fellowship program. Figure 1-3 displays the total award amounts by type from 2003 to 2015. Although awards are funded for multiple years, total award amounts in Figure 1-3 are assigned to the years of release of the funding announcements, so the total funds for each year do not match those in Figure 1-1. Individual-investigator grants have been awarded every year, but center grants and fellowships were not awarded yearly. In 2009 and 2014, no fellowships were awarded; and in 2006, 2010, and 2015, no center grants were awarded. Awards made in response to the 2015 RFAs were in progress during the preparation of the present report (EPA unpublished material 2016).

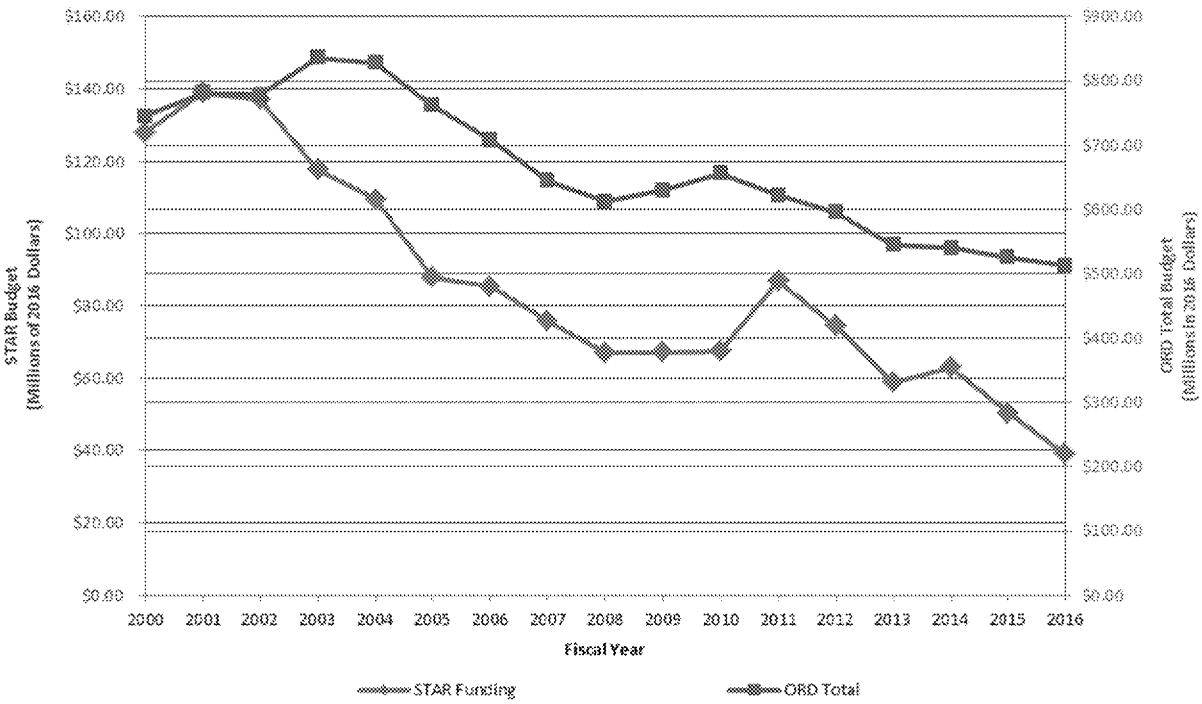

FIGURE 1-1 STAR program and ORD budgets. Source: Johnson 2016.

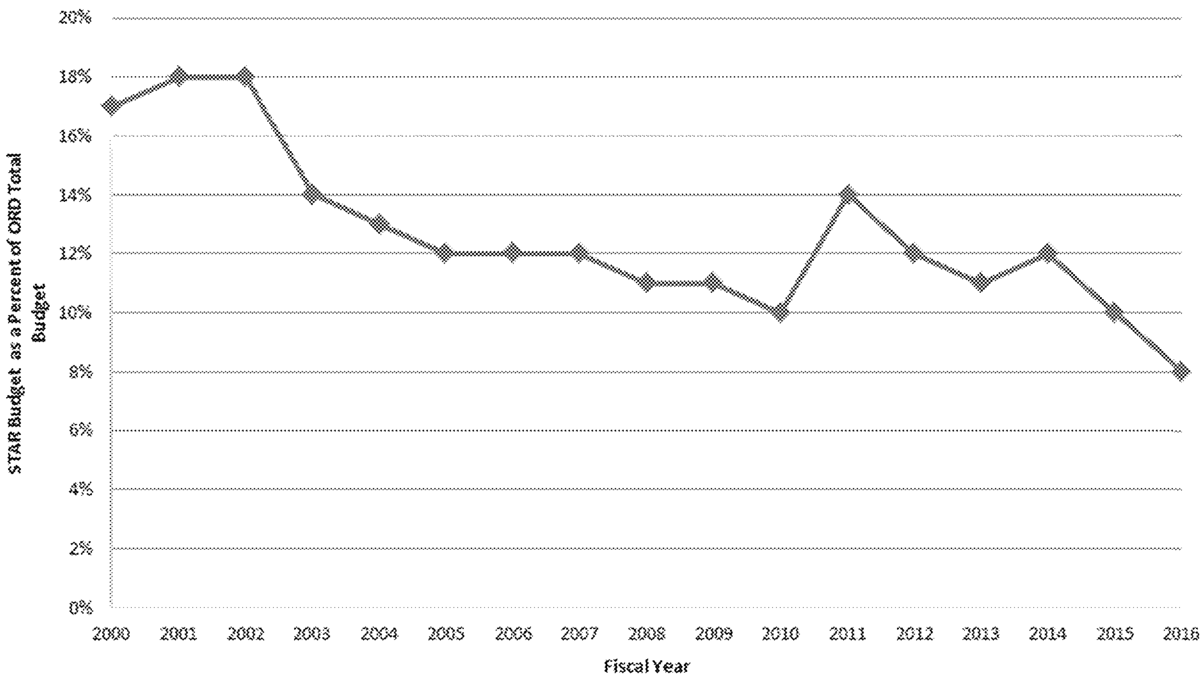

FIGURE 1-2 STAR program budget as a percentage of total ORD budget. Source: Johnson 2016.

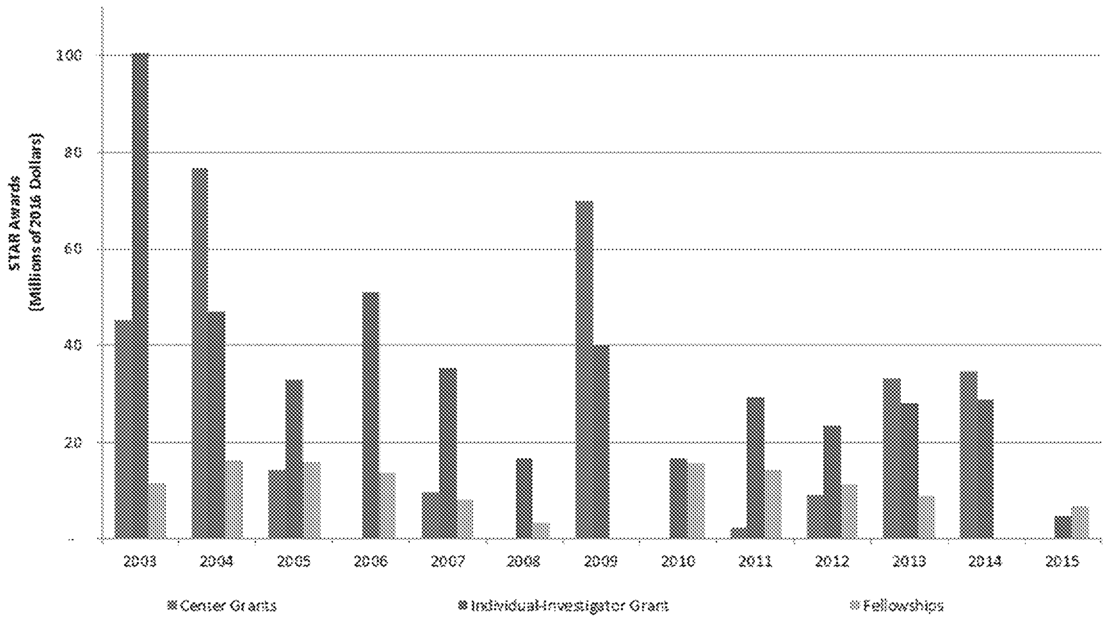

FIGURE 1-3 Types and numbers of STAR RFAs vary. Total award amounts shown here are associated with the year of RFA release. Awards are generally funded for multiple years. Source: EPA, unpublished material, 2016.

Individual-Investigator Grants

Individual-investigator awards are smaller project-based grants that provide funding to individuals or small teams of investigators. The proposals are submitted by universities, colleges, and nonprofit research institutions. Awards are usually for 2-3 years and range from just over $65,000 to just over $1 million (2016 dollars). The number of individual-investigator grants awarded has varied by year. For example, only 25 were awarded in 2008 but 192 in 2006. In 2015, the single RFA was issued which drew 32 applications, of which six were selected for funding.

Center Grants

Center grants fund multidisciplinary efforts involving many investigators working in complementary fields. The multidisciplinary nature of the centers allows research programs to incorporate different fields of expertise to tackle complex problems. For example, chemists, exposure scientists, epidemiologists, pediatricians, and child-development specialists explore the effects of environmental exposures on children's health and development. Often, several research organizations are involved in one center. Most center grants are funded for 5 years. The amount of an award varies, from less than $1 million to $10 million or more over 5 years; over half the center grants were for a total of over $4 million. No STAR center grants were awarded in 2015.

Fellowships

STAR graduate fellowships aimed to encourage promising students to pursue advanced degrees and careers in environment-related fields (NRC 2003). The number of fellowships awarded in 2003-2015 varied: 137 in 2010, zero in 2009 and 2014, and an overall average of 81 per year. In 2015, the fellowships provided up to $44,000 per year of support per fellowship. Master's-level students may receive support for a maximum of 2 years (that is, a maximum of $88,000). Doctoral students could be supported for a maximum of 3 years (a maximum of $132,000); the support could be received during a period of 5 years.

The fellowships were intended to defray costs associated with advanced, environmentally oriented study leading to a master's or doctoral degree. STAR fellowship applications could support the causes effects, extent, prevention, reduction, and elimination of all pollution across all media (air, water, soil) that adversely affect the environment and human health. The process for awarding of fellowships consisted of a peer review by non-EPA scientists and an internal programmatic review by EPA scientists of applications that received a final score of excellent in the peer review. The internal programmatic review aimed to ensure that applications were related to the EPA mission and would contribute to an integrated, balanced research portfolio (EPA 2015a).

In the 2016 budget, funding for STAR fellowships was eliminated (OSTP 2015). The STAR fellowships had been the only federal fellowships designed exclusively for students pursuing advanced degrees in environmental sciences and had aimed to build cohorts of environmental scientists who had the multidisciplinary backgrounds needed for addressing complex environmental-science problems. To consider the effects of the loss of the STAR program on the training of environmental and environmental health scientists, the number of NSF fellows in 2015 when the STAR program was still active was compared with the number in 2017, after the STAR program's cancellation. In 2015, NSF was supporting 168 fellows who were studying environmental sciences and engineering or ecology, and STAR was supporting 51 fellowships—a total of 219 total fellowships in environmental sciences (EPA 2015b, NSF 2017). In 2017, NSF awarded 176 fellowships in environmental sciences. Thus, after cancellation of funding of STAR fellowships, there were 43 fewer graduate fellowships in environmental and health sciences (NSF 2017).

Research Fields

To see how STAR's support of different fields evolved, the committee looked at the STAR budget related to ORD's four national programs: Air, Climate, and Energy (ACE), Chemical Safety and Sustainability (CSS), Safe and Sustainable Water Resources (SSWR), and Sustainable and Healthy Communities (SHC). Figure 1-4 displays the STAR funding of each national program in FY 2011-2015. The portion of the STAR budget received by each program was similar for each of the 5 years. SHC receives the largest portion of the STAR budget, with an average of 38%, followed closely by ACE, with an average of 30%. CSS and SSWR received an average of 21% and 11%, respectively.

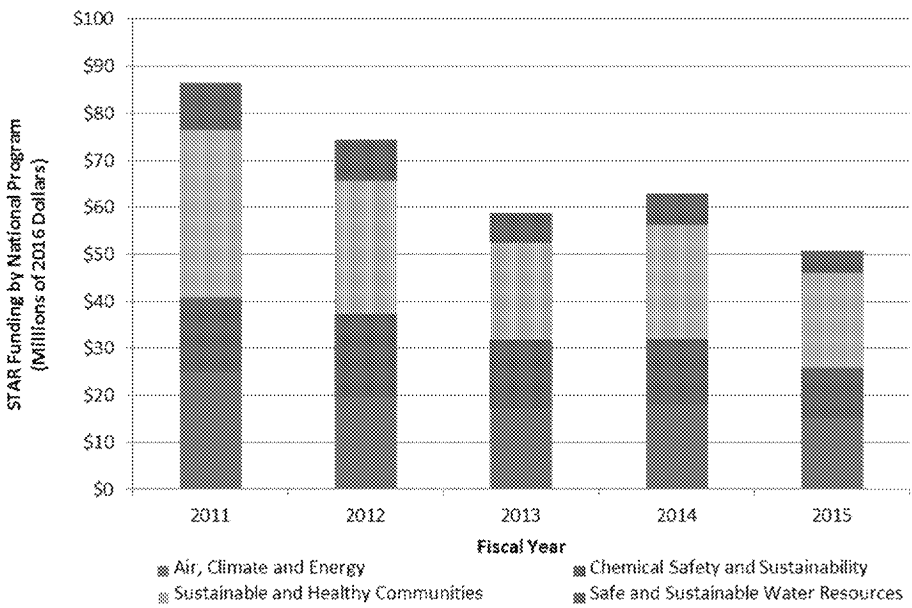

FIGURE 1-4 STAR funding of national programs. Source: EPA unpublished material 2016.

SUMMARY OF PREVIOUS REVIEWS OF THE SCIENCE TO ACHIEVE RESULTS PROGRAM

The STAR program has been reviewed many times since 2000. The reviews can be categorized as ones requested by EPA, ones that were part of EPA's planning and review procedures, and ones that were completed for an audit or external review purposes. Some reviews have been broad, with recommendations that affect the entire ORD program, which encompasses STAR; they offered such recommendations as developing roadmaps and goals for ORD programs and emphasizing the inclusion of social, behavioral, and decision sciences. Others have been narrower, focusing on specific elements, such as STAR fellowships. A common recommendation of the programmatic reviews has been to emphasize the importance of improving communication, dissemination, and outreach of STAR research results both in and outside EPA to other stakeholders. Some reviews have emphasized the importance of measuring the timeliness of the completion of grants and effectiveness.

The last scientific review of only the STAR program was the 2003 National Research Council review. It occurred after a 2000 request from EPA (NRC 2003). The reviewing committee analyzed information provided by EPA, STAR grant recipients and fellows, and other sources to assess the program's scientific merit and public benefits. The 2003 committee strongly endorsed the STAR program as an integral part of EPA's research program that provided the agency access to external and independent information, analyses, and perspectives. Box 1-1 summarizes the committee's key findings.

BOX 1-1 Summary of the Findings and Recommendations of 2003 National Research Council Committee to Review EPA's Research Grants Program

The committee found that the STAR program

- Funded important research that is not conducted or funded by other agencies.
- Used procedures for soliciting and selecting the highest-quality research proposals that compare favorably with the procedures established by other research agencies.
- Improved the scientific foundation for decision-making.
- Results were widely published in peer-reviewed journals.
- Effectively supported EPA's mission, Government Performance and Results Act goals, and the Office of Research and Development's strategic plans.
- Experimented with innovative approaches to communicate the results of its funded research to a wide variety of users and audiences.
- Enabled continuing training and supply of graduate students in environmental sciences through its fellowship program.

The committee recommended that EPA

- Institute a structured system of program-level reviews in the National Center for Environmental Research as its primary mechanism for evaluating the STAR program.
- Continue production of state-of- the-science and research-synthesis documents.
- Expand efforts to communicate with its diverse users and audiences.
- Maintain STAR program funding at 15-20% of the overall Office of Research and Development budget.
- Continue efforts to attract "the best and the brightest" researchers to compete for STAR funding.
- Continue funding for STAR fellowships given the nation's continuing need for highly qualified scientists and engineers in environmental research and management.

Other scientific reviews that covered STAR include those of ORD's research program by the EPA Board of Scientific Counselors (BOSC) and Science Advisory Board (EPA SAB/BOSC 2011, 2012; EPA BOSC 2016). The latter reviews were conducted as part of the planning and review procedures established in ORD. The STAR program was not the focus of the reviews, but the reports included recommendations that would affect it. For example, the most recent of the reviews included all ORD programs and thereby affected the STAR program. Suggestions include developing measures of success for outputs and outcomes of each program. The review also suggested that EPA further develop and enhance efforts in research synthesis and translation, continue to nurture and expand cross-program and transdisciplinary integration to increase efficiencies and synergies, and maintain alignment between research focused on short-term goals and research focused on long-term objectives.

The STAR program was audited recently by EPA's Office of the Inspector General (OIG) (EPA 2016). The OIG report recommended that ORD identify the direct and incidental benefits of the STAR program. STAR was requested to have procedures in place for conducting and evaluating relevance reviews and for soliciting and considering input from program offices. OIG's recommendations were based on an extensive survey of the ORD staff and management. The BOSC review had emphasized the need to be clear about the use of such key terms as *partners*, *stakeholders*, and *end users* at ORD. The report also encouraged ORD to foster greater cross-program and transdisciplinary integration. This review and others and EPA's responses are summarized individually in Appendix B.

THE CURRENT REVIEW

The director of NCER approached the National Academies of Sciences, Engineering, and Medicine Board on Environmental Studies and Toxicology about conducting an independent assessment of the STAR program. To conduct the study, the Academies convened the Committee on the Review EPA's Research Grants Program, which prepared the present report. The committee's members were selected for expertise in toxicology, epidemiology, public health, exposure science, environmental science and engineering, ecology, sustainability, risk assessment, and research management and program evaluation. (See Appendix A for committee membership and biographies.) None of the committee members was a current recipient of a STAR grant, nor did any committee member apply for a STAR grant during the course of the study.

The committee was charged with conducting a program review of STAR. Its statement of task is provided in Box 1-2.

BOX 1-2 Statement of Task

An ad hoc Committee will review the EPA's Science to Achieve Results (STAR) competitive extramural research grants program. The Committee will assess the program's scientific merit, benefits to the public and overall contributions in the context of other relevant research. The Committee will compare the benefits of the STAR program with the benefits of other scientific research grant programs. The Committee will recommend ways to enhance the program's scientific merit, impact of its results, and other benefits.

The Committee will also consider:

- The conclusions and recommendations of the 2003 NAS review of the STAR program.
- The STAR program's research priorities in light of the Nation's ongoing and emerging environmental challenges.
- Effects of recent STAR funding trends on obtaining scientific information needed to protect public health and the environment.

THE COMMITTEE'S APPROACH

Although the statement of task refers to the STAR competitive extramural grants program, the committee interpreted that to include the fellowship program because the fellowship program had been a long-standing integrated component of STAR. It evaluated the program as a whole and did not systematically evaluate the quality of individual research grants. It used the three components from the statement of task to guide its approach: assess the STAR program's scientific merit, assess the program's public benefits, and assess the program's contribution to the nation's important environmental research needs.

To assess whether STAR procedures sponsor research of high scientific merit the committee compared STAR's operating procedures for determining topics for priority-setting, developing funding announcements, and the procedures for the review and award of grants with those of other extramural research programs that fund research in similar fields. The committee also read all STAR RFAs released from 2003 to 2015; each committee member read about seven RFAs.

To assess the program's public benefits, the committee created a logic model. A logic model is a visual depiction of how a program is designed to achieve its goals (McLaughlin and Jordan 2015). In the case of STAR, the goals include only indirect benefits to EPA in that through the Federal Grants and Cooperative Agreement Act of 1977 grants cannot directly benefit federal agencies (Engel-Cox et al. 2008). Then the committee reviewed metrics for points along the model to consider the ability of the STAR program to achieve its goals.

To assess STAR's contribution to the nation's important environmental research needs, the committee first considered the landscape of environmental research and the specific scientific fields that are important for contributing to environmental knowledge and capacity and thus addressing environmental challenges. Then the committee contemplated how STAR contributes in a distinctive way.

The remainder of this report is organized into four chapters. Chapter 2 covers the assessment of the STAR program's scientific merit, Chapter 3 the committee's assessment of the STAR program's public benefits, and Chapter 4 the committee's assessment of STAR's contribution to the nation's important environmental research needs. Chapter 5 presents the committee's findings and recommendations.

REFERENCES

BLS (U.S. Bureau of Labor Statistics). 2016. Consumer Price Index Inflation Calculator [online]. Available: https://www.bls.gov/data/inflation_calculator.htm [accessed January 18, 2017].

Boyd, G.A. 2005. A method for measuring the efficiency gap between average and best practice energy use: The ENERGY STAR industrial energy performance indicator. J. Ind. Ecol. (3):51-65.

Cohen, A.J., M. Brauer, R. Burnett, H.R. Anderson, J. Frostad, K. Estep, K. Balakrishnan, B. Brunekreef, L. Dandona, R. Dandona, V. Feigin, G. Freedman, B. Hubbell, A. Jobling, H. Kan, L. Knibbs, Y. Liu, R. Martin, L. Morawska, C.A. Pope, III, H. Shin, K. Straif, G. Shaddick, M. Thomas, R. van Dingenen, A. van Donkelaar, T. Vos, C.J.L. Murray, and M.H. Forouzanfar. 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015. Lancet 389(10082):1907-1908.

Engel-Cox, J.A., B. Van Houten, J. Phelps, and S.W. Rose. 2008. Conceptual model of comprehensive research metrics for improved human health and environment. Environ. Health Perspect. 116 (5):583-592.

EPA (U.S. Environmental Protection Agency). 1980. ORD Extramural Program Guide FY 1981. EPA 600/9-80-052. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC. October 1980.

EPA. 1997. The Benefits and Costs of the Clean Air Act 1970 to 1990 [online]. Available: https://www.epa.gov/sites/production/files/2015-06/documents/contsetc.pdf [accessed January 17, 2017].

EPA. 2007. A Decade of Children's Environmental Health Research: Highlights from EPA's Science to Achieve Results Program. EPA/600/S-07/038. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC [online]. Available: https://www.epa.gov/sites/production/files/2015-09/documents/decade-of-childrens-health-full-report.pdf [accessed January 17, 2017].

EPA. 2015a. Science to Achieve Results (STAR) Fellowships for Graduate Environmental Study Funding Opportunity Announcement. Office of Research and Development, National Center of Enviornmental Research, U.S. Environmental Protection Agency, Washington, DC [online]. Available: https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.rfatext/rfa_id/579 [accessed April 27, 2017].

EPA. 2015b. STAR Graduate Fellowships Request for Applications Closing Date: May 26, 2015 [online]. Available: https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/recipients.display/rfa_id/579 [accessed January 18, 2017].

EPA. 2016. EPA Offices Are Aware of the Agency's Science to Achieve Results Program, but Challenges Remain in Measuring and Internally Communicating Research Results That Advance the Agency's Mission. Report No. 16-P-0125. Office of Inspector General, U.S. Environmental protection Agency, Washington, Dc [online]. Available: https://www.epa.gov/sites/production/files/2016-03/documents/20160330-16-p-0125.pdf [accessed May 16, 2017].

EPA BOSC (U.S. Environmental Protection Agency, the Board of Scientific Councilors). 2016. Review of EPA Office of Research and Development's Research Programs. January 8, 2016 [online]. Available: https://www.epa.gov/sites/production/files/2016-03/documents/bosc_report_02-29-2016_final.pdf [accessed January 18, 2017].

EPA SAB/BOSC (U.S. Environmental Protection Agency Science Advisory Board and the Board of Scientific Councilors). 2011. Office of Research and Development (ORD) New Strategic Research Directions. October 2011 [online]. Available: https://www.epa.gov/sites/production/files/2015-03/documents/stratresdir111021rpt.pdf [accessed January 18, 2017].

EPA SAB/BOSC. 2012. Implementation of ORD Strategic Research Plans. September 2012 [online]. Available: https://www.epa.gov/sites/production/files/2015-02/documents/120928rpt.pdf [accessed January 18, 2017].

Johnson, J. 1996. Rebuilding EPA science. Environ. Sci. Technol. 30(11):492A-497A.

Johnson, J. 2016. Presentation at the First Meeting on Review of EPA's Science to Achieve Results' Research Grants Program, June 21, 2016, Washington, DC.

McLaughlin, J.A., and G.B. Jordan. 2015. Using logic models. Pp. 62-87 in Handbook of Practical Program Evaluation, 4th Ed., K.E. Newcomer, H.P. Hatry, and J.S. Wholey, eds. Hoboken, NJ: John Wiley & Sons, Inc.

Landrigan, P.J., C.B. Schechter, J.M. Lipton, M.C. Fahs, and J. Schwartz. 2002. Environmental pollutants and disease in American children: Estimates of morbidity, mortality, and costs for lead poisoning, asthma, cancer, and developmental disabilities. Environ. Health Perspect. 110(7):721-728.

NRC (National Research Council). 1997. Building a Foundation for Sound Environmental Decisions. Washington, DC: National Academy Press.

NRC. 2000. Strengthening Science at the U.S. Environmental Protection Agency. Washington, DC: National Academy Press.

NRC. 2003. The Measure of STAR: Review of the U.S. Environmental Protection Agency's Science to Achieve Results (STAR) Research Grants Program. Washington, DC: The National Academies Press.

NRC. 2008. Evaluating Research Efficiency in the U.S. Environmental Protection Agency. Washington, DC: The National Academies Press.

NRC. 2012. Science for Environmental Protection: The Road Ahead. Washington, DC: The National Academies Press.

NRC. 2014. Rethinking the Components, Coordination, and Management of the U.S. Environmental Protection Agency Laboratories. Washington, DC: The National Academies Press.

NSF (National Science Foundation). 2013. Federal Funds Survey Glossary. https://www.nsf.gov/statistics/fedfunds/glossary/def.htm#basic [accessed January 18, 2017].

OSTP (Office of Science and Technology Policy). 2015. Progress Report on Coordinating Federal Science, Technology, Engineering, and Mathematics (STEM) Education. Executive Office of the President of the United States, Washington, DC [online]. Available: https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_ed_budget_supplement_fy16-march-2015.pdf [accessed January 18, 2017].

Sun, S., J.H. Schiller, and A.F. Gazdar. 2007. Lung cancer in never smokers – A different disease. Nat. Rev. Cancer 7(10):778-790.

Walsh, C.J., T.D. Fletcher, and A.R. Ladson. 2005. Stream restoration in urban catchments through redesigning stormwater systems: Looking to the catchment to save the stream. J. N. Am. Benthol. Soc. 24(3):690-705.

Witt, C.E. 2003. It makes sense because it makes cents. Mater. Handl. Manage. 58(3):14.

2

The Scientific Merit of the Science to Achieve Results Program

The committee assessed the scientific merit of the Science to Achieve Results (STAR) program by evaluating whether the program had appropriate procedures in place to produce high-quality research. As described in the section on the committee's approach in Chapter 1, it conducted its evaluation by comparing the STAR program's procedures with procedures from selected other extramural research programs. The committee also read the requests for applications (RFAs) put out by the STAR program and it looked at the Environmental Protection Agency (EPA) grantee-project results database.

A number of public and private organizations support research on human health and the environment. The committee obtained relevant information about other extramural research programs through a combination of methods, including review of procedures posted on research-program Web sites, study of presentations provided to the committee, and communication via e-mail with program administrators. Table 2-1 shows the research programs selected for comparison with STAR, including brief descriptions of the research fields covered and the budgets. The committee chose the programs listed in Table 2-1 because they support research on topics somewhat similar to those supported by STAR. The committee also wanted to include a few grants programs administered by federal agencies with regulatory authority, because grants are for the benefit of the nation and not the sponsoring agency (Federal Grants and Cooperative Agreement Act of 1977). The programs vary in size, scope, and purpose. The California Air Resources Board (ARB) program was created to provide science-informed air-pollution policies and regulations. The Health Effects Institute (HEI) is an independent research organization which was created to provide high-quality, impartial, and relevant science on the health effects of air pollution; it is funded through grants from EPA and through funding from the automobile industry. Two other programs, the National Oceanic and Atmospheric Administration (NOAA) National Centers for Coastal Ocean Science (NCCOS) and the US Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA), are administered by federal agencies to support science related to their missions, and two, the National Science Foundation (NSF) Division of Earth Sciences and the National Institute of Environmental Health Sciences (NIEHS) Division of Extramural Research and Training (DERT) have a principal mission of supporting basic research and the progress of science itself.

PRIORITY-SETTING

Priorities for STAR are set through 4-year strategic research action plans (StRAPs) for the national programs: Air, Climate, and Energy; Chemical Safety for Sustainability; Safe and Sustainable Water Resources; and Sustainable and Healthy Communities. EPA develops the StRAPs through a comprehensive 2-year planning process. The StRAPs are reviewed before implementation and again in the first year of implementation by two external scientific bodies: the Science Advisory Board, which comments on EPA's strategic directions, and the Board of Scientific Counselors (BOSC), which evaluates the quality of the science delivered. The process begins again 2 years into the implementation of the plans. The Office of Research and Development (ORD) has established standing subcommittees of the BOSC for each of the national programs.

TABLE 2-1 US Extramural Research Programs Selected for Comparison with STAR

Research Program	Program Description	Approximate 2016 Annual Budget	Parent Agency or Department Has Regulatory Authority
EPA STAR	The underlying scientific and engineering knowledge needed to address environmental and human health issues and improve decision-making, problem detection, and problem-solving.	$39 million	Yes
California Air Resources Board	Research to support regulations related to air quality and climate change	$4-8 million	Yes
Health Effects Institute	Health effects of air pollution	Total: $10-12 million; $5 million from EPA	No
National Institute of Environmental Health Sciences Division of Extramural Research and Training	Basic and translational research to understand how the environment influences human health and disease	About $400 million, including Superfund Research Program	No
National Oceanic and Atmospheric Administration National Centers for Coastal Ocean Science	Research on coastal science	$9 million	Yes
National Science Foundation Division of Earth Sciences	Research geared toward improving understanding of the structure, composition, and evolution of Earth, the life that it supports, and the processes that govern the formation and behavior of its materials (NSF 2017)	$181 million	No
US Department of Agriculture National Institute of Food and Agriculture	Research to support investment in and advancement of agricultural research, education, and extension to address societal challenges	$1.5 billion	Yes

Each national research program is led by a national program director (NPD) that identify the high-priority research topics, key science questions, and the times when the outputs are needed. The research is then implemented by EPA's laboratories and centers which determine the research team and the science needed to address the priorities. The NPDs work with other staff in ORD to ensure the resources are appropriately allocated to support the approved projects to be implemented by the laboratories and centers. STAR projects are integrated into this planning process.

Other regulatory agencies that have research programs use slightly different planning mechanisms. The California ARB includes an open call to the public for research ideas. The research ideas are ranked by program needs and available funding and coordinated with other funding organizations to avoid duplication and to leverage funds. The California ARB Research Screening Committee reviews an annual research plan, which is also open for public comment. The Research Screening Committee consists of external scientists, engineers, and others who are knowledgeable, technically qualified, and experienced in air-pollution and climate-change problems. The annual research plan is then adopted by the ARB at a public hearing.

HEI defines its research agenda as it develops its strategic plan. The strategic plan sets the funding priorities for the next 5 years, and HEI's board approves the strategic plan. HEI coordinates research topics with EPA to avoid duplicate funding.

NOAA's NCCOS looks for opportunities that have the greatest chance of achieving useful outcomes for coastal management. NCCOS coordinates with other NOAA National Ocean Service offices, the coastal-management community, and other federal agencies and stakeholders. It develops prospectuses that articulate coastal-management research needs, who will use the information, and the pathways to application, outputs, and outcomes. The prospectuses are vetted within NOAA by leaders and other partners that have overlapping interests or expertise to ensure that the chosen research priorities are clearly and strategically targeted to achieve management outcomes.

USDA NIFA develops research priorities through its 58 national program leaders and 4-year strategic plans. The program leaders consider inputs from numerous parties, including commodity groups, industry, interagency federal work groups, the National Academies, nongovernment organizations, scientific societies, and university partners (NRC 2014).

At NIEHS, DERT develops broad program priorities and recommends funding levels to ensure maximal use of available resources to attain institute objectives. Through cooperative relationships within the National Institutes of Health (NIH) and with public and private institutions and organizations, the division aims to maintain an awareness of national research efforts and assesses the need for research and research training in environmental health (NIEHS 2015).

NSF priority-setting seems to be set around broad topics that are highlighted in the agency's 4-year strategic plan (NSF 2014a). In the divisions, the priorities typically cover a mix of projects that focus on basic-science concepts that can include environmental issues addressed by individual scientists or engineers or through multidisciplinary approaches. Ideas have a variety of sources, such as conferences and workshops, National Academies' studies, national mandates, congressional budgetary guidance, the findings of other scientific research studies, and NSF program officers and directors.

None of the research programs uses exactly the same mechanism for priority-setting. The EPA process for STAR leads to a research program that is arguably more defined than that of a nonregulatory agency, such as NSF and NIEHS, and it appears to be more coordinated with the agency's own research program than USDA's NIFA or NOAA's NCCOS. In contrast, such narrowly focused programs as those of the California ARB, HEI, and NCCOS have agendas more defined than that of STAR.

FUNDING ANNOUNCEMENTS

The STAR program has a defined process for developing RFAs and advertises funding announcements broadly. The program takes a year or less to develop an individual funding announcement. The process begins with a meeting to discuss the ideas for the announcement; EPA then assembles a writing team that writes the RFA, which is reviewed by EPA management before being opened to receive applications. During that time, there may be discussions with other federal agencies to combine funds when agencies share an interest. That step includes coordination with the EPA NPDs and other ORD program managers who establish the priorities for funding grants. Other research programs that STAR has partnered with include NSF, NIOSH, NIEHS, DOE, the Department of Homeland Security, USDA, and the UK Environmental Nanoscience Initiative. EPA advertises funding announcements on its Web site and in the *Federal Register*. They are also disseminated at professional meetings, distributed on various e-mail lists, and advertised on such social-media outlets as Twitter and Facebook.

Other research programs develop their RFAs or funding announcements in their own ways. HEI's Research Committee develops RFAs on the basis of input gathered from intensive expert workshops and from sponsors. HEI also accepts investigator-initiated proposals on the broad topic of air pollution from mobile sources. Similarly, the California ARB Research Screening Committee reviews and approves RFA objectives. The California ARB and HEI post announcements on their Web sites and e-mail services.

In NIEHS, each branch has a different process for the development of RFAs, but most branches involve consultation among the extramural staff, management-level approval, and concept approval by an external advisory committee. NIEHS allows both solicited applications, such as responses to RFAs as described above, and unsolicited (investigator-initiated) applications that are submitted to request funding for projects of interest to the submitting researcher, which may be related to any research topic within the mission of NIH (NIEHS 2015). NIEHS funding announcements are widely distributed, including posting on the agency's Web site (grants.nih.gov), on e-mail lists, and on social media.

NCCOS's staff officers develop funding announcements to provide detailed information for proposers and meet the criteria established in NOAA's grants manual. NCCOS releases funding opportunities on a federal Web site (grants.gov) and on its own Web site.

It is standard in NSF to receive unsolicited applications that are submitted to request funding for projects of interest to the submitting researcher. Funding announcements are becoming more common. NSF program officials develop broadly framed funding announcements on the basis of a process that involves consultation with other programs in NSF, coordination with other stakeholders, and approval by managers. NSF funding opportunities are also announced widely on government Web sites, e-mail lists, and social media.

USDA RFAs are prepared by the RFA writing group, which comprises national program leaders and program specialists. The approval chain consists of the leaders of the relevant institute, senior executives (the Science Leadership Council), the Policy Office, and the Office of the Chief Scientist in NIFA (NRC 2014).

Like the other grant programs considered, EPA STAR has a well-established and responsive internal process for developing funding announcements. STAR also coordinates well with other agencies to leverage funds and avoid unnecessary duplication. STAR differs from NSF, NIEHS, the California ARB, and HEI in that it appears to have no mechanisms for submission of unsolicited proposals or ideas for research.

PROPOSAL REVIEW AND AWARDING OF GRANTS

After RFAs are developed and released, STAR provides academic investigators about 2 months to submit proposals, longer for some large center RFAs. Once received, proposals undergo several types of review: administrative review to verify that the application meet the requirements described in the RFA, peer-review for scientific merit, past-performance history review, and relevance review. Peer-review of STAR grants is performed by ad hoc external review panels. The panels include academic, government, or private sector scientists who are knowledgeable about the scientific subject of the RFA and meet the conflict-of-interest (COI) requirements.

At several points throughout the peer-review process, COI issues are checked and documented. In the inquiry e-mail, interested expert reviewers are asked to report any potential COI concerns. For example, potential peer-reviewers are asked whether they will be part of a team submitting an application in response to the RFA and whether an application will be submitted by their own institution. EPA scientific-review officers evaluate reviewers' CVs and professional Web pages before assigning applications to reviewers. Once applications are available to reviewers, reviewers are required to check their assigned applications and to give notice immediately if there are unforeseen COI concerns.

External peer-reviewers are named as primary or secondary reviewers, receive copies of the proposals, and meet to discuss and assign a score to each proposal. Highly scored proposals are reviewed further for past performance and relevance. In December 2016 (subsequent to the committee's final meeting), EPA finalized a new procedure for relevance review. The relevance review is completed within 4 weeks of the peer-review meeting. Much like peer-reviewers, relevance-review panelists are chosen on the basis of expertise in the scientific fields of the applications being reviewed. However, relevance-review panels consist only of EPA staff and include cross-agency representation (regional offices, ORD, and non-ORD program offices are all represented). Like peer-reviewers, relevance reviewers are screened for potential COI. Each application is to be reviewed by at least three reviewers, sometimes five for larger centers; one reviewer serves as a rapporteur and is responsible for the discussion of the RFA at the panel meeting. The criteria for the reviews are those listed in the RFA. After the panel meeting, the application scores are recorded and provided to program officers.

The research programs of the California ARB and HEI have processes that use steps similar to those of STAR: an internal administrative review, a peer-review, and a programmatic review. There are some differences in the peer-review process. In the California ARB, program staff and interagency project teams recommend proposals for funding, and peer-review oversight is completed by the Research Screen-

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ing Committee. HEI proposals are reviewed by a special review panel that includes the Research Committee and external subject-matter experts who are not affiliated with the applicants. Those experts score according to scientific merit, qualifications, and responsiveness to the RFA. Successful applications are then subjected to a programmatic review by the Research Committee, which makes the final award decisions. In both those research programs, the programmatic review includes an evaluation of past performance of the grantee and of the relevance of the proposed research to the program's mission.

All NOAA NCCOS grant applications are reviewed by an ad hoc committee of reviewers selected on the basis of their qualifications and expertise in the topic; the reviewers are screened for COI in accordance with criteria established in NOAA's grants manual. After review and scoring of applications, the NOAA program officer has discretion as to which applications to award.

The NIEHS peer-review process is different from that used by STAR and involves two steps. The first review is by the study section, which is a standing committee composed of external scientific reviewers who meet to review the scientific and technical merit of applications. The second includes the National Advisory Environmental Health Sciences (NAEHS) Council, which comprises appointed external expert scientists and internal NIEHS staff. Only applications that are recommended by both the study section and the NAEHS Council may be recommended for funding (NIEHS 2015).

The NSF proposal review and award procedures include peer-review by a committee of external scientists. NSF differs slightly in that proposals are reviewed for broader impacts in addition to intellectual merit. In some cases, other criteria are considered. The external reviewers' analyses of the proposals are provided to the program officer, who makes recommendations to the division director; applications that are successfully reviewed by the division director are forwarded for a business review and then final decision on an award.

USDA's NIFA uses a peer-review process in which panel managers and national program leaders assigned to each program area are responsible for review of proposals. Panel managers are part-time, temporary USDA employees who are recruited for the sole purpose of managing proposal review, whereas national program leaders are full-time, permanent USDA employees. The USDA program differs from the other programs included here in that its peer-review process is the only criterion that the program uses to make funding decisions (NRC 2014).

All the agencies reviewed use a competitive peer-review process, although there are differences in the peer-review procedures, such as the use of ad hoc peer-review committees (in EPA, NSF, and NCCOS) vs standing committees (in HEI, ARB, and NIEHS) or the inclusion of agency staff in the process (in USDA). Many agencies have a review step following peer-review. EPA was the only research program in this comparison that had a relevance review that is decoupled from other aspects of the programmatic review.

GRANT AWARD RATE

Figure 2-1 shows the percentage of STAR applications that were awarded in 2003-2014, as defined by the number of awardees per year divided by the number of applications received per year. The median rate over the last 13 years was 16% (in 2005), the lowest 12% (in 2010), and the highest 32% (in 2003). NIEHS had an award rate of 14.7% in 2015 (NIH 2015), NSF 23% in 2014 (NSF 2014b), and USDA 14.8% in 2014 (USDA NIFA 2014).

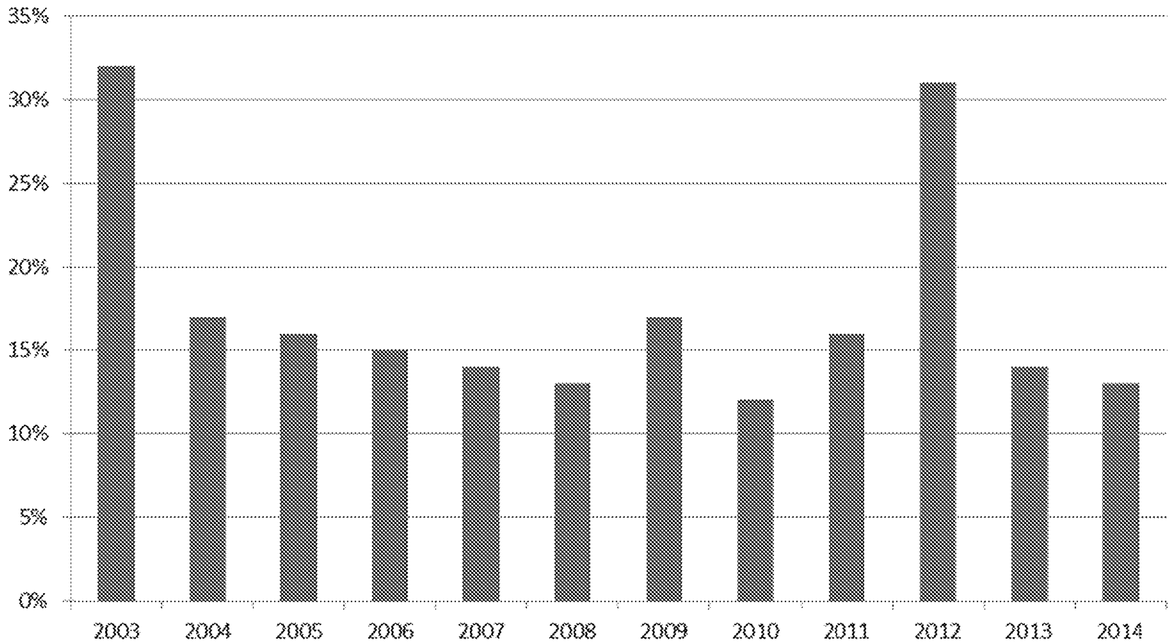

FIGURE 2-1 Grant award rate of STAR RFAs (number of awarded grants divided by number of applications), 2003-2014. Source: EPA unpublished data 2016.

MANAGEMENT

In the STAR program, each awarded grant is assigned to a project officer, who tracks the progress of the project. Regular annual progress reports and a final report of both the scientific and financial aspects of the project are tracked by the project officer. EPA collects lists of all publications that result from each project. The STAR program also maintains a Grantee Research Projects Results Web page (https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/search.welcome) in which it lists STAR research grants awarded in a particular research field and reports research outputs and project results.

STAR grant investigators for a specific RFA topic typically meet annually to circulate new information among the investigators and EPA scientists. For larger center programs, the STAR grantees hold public webinars in which investigators present research findings to the public and other stakeholders. In some cases, discussions are held between EPA scientists and grant awardees to determine whether additional collaborations would be beneficial in increasing information transfer and facilitating the research.

HEI and the California ARB issue contracts, not grants, and are more involved in the research process. ARB has quarterly progress meetings, review of draft manuscripts, and Research Screening Committee peer-review of draft final reports. In HEI, investigators conduct research with direct committee oversight; comprehensive reports include all results, both positive and negative.

Management of grantees by NIEHS is overseen by the grants management staff to ensure adherence to all applicable NIH and other federal government rules and policies. Grantees typically submit progress reports annually, and scientific progress must be determined to be satisfactory by program administrators before additional funds can be awarded for continuation of a project. For some projects and programs, there are periodic meetings and public webinars to facilitate collaborations and information transfer to the public.

NSF also requires annual reporting by grantees and a final report when a grant is completed. As with NIH, failure to submit timely reports will delay processing of additional funding. NSF also requires a project outcomes report for the general public that must be submitted within 90 days after expiration of the grant. That report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project.

The management procedures used by EPA appear very similar to those of other research programs that issue grants. There seems to be a trend among grant funding agencies to have meetings, workshops, and webinars to facilitate collaboration.

COMMITTEE'S EVALUATION

The committee's review of the STAR RFAs released by EPA from 2003 to 2015 revealed that the RFAs generally have well-described goals (90%) and explicit review criteria (90%). The research topics are as broad as EPA's mission and include topics as varied as computational toxicology, microbial risk assessment, mitigation of oil spills, and creation of children's environmental-health centers (Appendix C lists RFA titles). Most of the requests are in fairly specific focused research fields (over 80%), although the program has put forward some more general requests. The goals of the research effort also vary widely, for example, developing new technologies, developing research centers, and advancing knowledge and tools. As a result, the stakeholders vary widely—policy-makers and risk assessors at the local, state, and federal levels; the manufacturing industry; and the environmental research community.

The committee also reviewed a list of the scientists who had served on the STAR peer-review committees and their affiliations. To protect their confidentiality, EPA could not disclose the specific RFA peer-review committee on which each scientist served. In reviewing the names and affiliations of the reviewers, however, the committee was favorably impressed by the expertise represented. It was unclear whether investigators received scores or feedback from relevancy review.

The STAR grant-proposal award rate in recent years has been notable for its competitiveness, which may signify that the program sponsors research in areas that have a high demand, and is a measure of the vitality of a sponsored-research program (Cushman et al. 2015; von Hippel and von Hippel 2015). However, given the long-term trend of declining grant-award rates in most US federal research programs, the low probability of award is now the concern most noted by those who study the US research enterprise (Rockey 2014; Cushman et al. 2015; Noailly 2016). A number of adverse effects have been attributed to overcompetitive research funding, which can foster proposals, reviews, and publication practices that discourage the most innovative science (Berezin 2001; Stephan 2012; Edwards and Roy 2017). Interdisciplinary research of the type needed to address many environmental issues and yield high-impact products (Chen et al. 2015) is especially vulnerable to reduction in funding and award rates (Lyall et al. 2013; Bromham et al. 2016). Award rates that are too low can both discourage the broader participation of researchers in the field and decrease incentives for innovation.

What is an appropriate target for an acceptable grant proposal-award rate to maintain an innovative environmental research program that is responsive to critical knowledge needs? Cushman et al. (2015) summarized recent studies and concluded that a 30-35% grant award rate is ideal, but programs can sustain reductions down to 20% before researchers, especially those new to the field (often those most innovative), are discouraged from participating. Many US research programs, including STAR, are now below 20%. Cushman et al. further suggested that a rate of 6% is essentially an absolute minimum, at which the chance of success of a submission no longer justifies the time needed to develop and submit a responsive proposal. The committee speculates that one reason STAR has not become overcompetitive, is that the RFAs released are specific, and fewer researchers could develop a grant proposal to respond to the RFA.

The committee reviewed the STAR grantee project results on the aforementioned Web site. It found that the data were incomplete. There were many examples of individual principal-investigator grants long completed or at least in operation for a number of years on which annual or final reports are unavailable. It is unclear why the project Web site is not updated.

CONCLUSIONS

The committee found that the STAR program's procedures contain elements similar to those of comparable research programs that the committee chose to examine. It is notable that STAR is one of the few programs that do not allow unsolicited proposals or the inclusion of RFA topic ideas from the many external stakeholders public. The committee acknowledges that EPA may have chosen to rely on focused research questions through RFAs, because it is easier to integrate STAR's priorities then within its own intramural research program. The committee also thought it was appropriate that EPA integrated the priority setting procedures for STAR within four of ORD's national programs; this allows STAR to remain flexible in light of what EPA sees as the nation's needs and avoids concerns of STAR being duplicative of EPA's internal research. The committee noted that STAR was the only program that did not allow the general public to submit research topic ideas, or unsolicited proposals, which may limit the creativity of the program. Another adverse implication of the priority-setting process is that as the budget for ORD has declined (see Figure 1-1), the budget for STAR has declined even faster; this may be due to the defining of STAR's budget according to the four national programs instead of directly for STAR itself.

The STAR program puts out RFAs that are generally of good quality and in a wide variety of topics. The peer-review process used by STAR is rigorous and conducted by qualified scientists. The committee thinks it may be worthwhile for the applicants to receive feedback on the relevancy reviews. The committee noted that many project reports were missing from the grantee project results Web site, which concerned some committee members. EPA should fix this Web site.

REFERENCES

Berezin, A.A. 2001. Discouragement of innovation by overcompetitive research funding. Interdiscipl. Sci. Rev. 26(2):97-102.

Bromham, L., R. Dinnage, and X. Hua. 2016. Interdisciplinary research has consistently lower funding success. Nature 534(7609):684-687.

Chen, S., C. Arsenault, and V. Larivière. 2015. Are top-cited papers more interdisciplinary? J. Informetr. 9(4):1034-1046.

Cushman, P., J.T. Hoeksema, C. Kouveliotou, J. Lowenthal, B. Peterson, K.G. Stassun, and T. von Hippel. 2015. Impact of declining proposal success rates on scientific productivity. arXiv preprint arXiv:1510.01647.

Edwards, M.A., and S. Roy. 2017. Academic research in the 21st century: Maintaining scientific integrity in a climate of perverse incentives and hypercompetition. Environ. Eng. Sci. 34(1):51-61.

Lyall, C., A. Bruce, W. Marsden, and L. Meagher. 2013. The role of funding agencies in creating interdisciplinary knowledge. Sci. Public Policy 40(1):62-71.

NIEHS (National Institute of Environmental Health Sciences). 2015. Division of Extramural Research and Training (DERT) Overview and Highlights [online]. Available: https://www.niehs.nih.gov/research/supported/dert/index.cfm [accessed January 18, 2017].

NIH (National Institutes of Health). 2015. Table 205. Reseach Project Grants and Other Mechisms Success Rates [online]. Available: http://report.nih.gov/success_rates.

Noailly, J. 2016. Research funding: Patience is a virtue. Nat. Energy 1(4):16038.

NRC (National Research Council). 2014. Spurring Innovation in Food and Agriculture: A Review of the USDA Agriculture and Food Research Initiative Program. Washington, DC: The National Academies Press.

NSF (National Science Foundation). 2014a. Investing in Science, Engineering, and Education for the Nation's Future: Strategic Plan for 2014-2018 [online]. Available: https://www.nsf.gov/pubs/2014/nsf14043/nsf14043.pdf [accessed May 17, 2018].

NSF (National Science Foundation). 2014b. Report to the National Science Board on the National Science Foundation's Merit Review Process-Fiscal Year 2013. May 2014 [online]. Available: https://www.nsf.gov/pubs/2014/nsb1432/nsb1432.pdf [accessed January 18, 2017].

NSF. 2017. About Earth Science [online]. Available: https://www.nsf.gov/geo/ear/about.jsp [accessed May 17, 2017].

Rockey, S. 2014. Comparing success rates, award rates and funding rates. RockTalk, NIH Extramural Nexus, March 5, 2014 [online]. Available: https://nexus.od.nih.gov/all/2014/03/05/comparing-success-award-funding-rates/ [accessed January 18, 2017].

Stephan, P. 2012. Research efficiency: Perverse incentives. Nature 484(7392):29-31.

USDA NIFA (U.S. Department of Agriculture, National Institute of Food and Agriculture). 2014. AFRI 2014 Synopsis Data [online]. Available: https://nifa.usda.gov/afri-2014-synopsis-data [accessed January 18, 2017].

von Hippel, T., and C. von Hippel. 2015. To apply or not to apply: A survey analysis of grant writing costs and benefits. PLoS ONE 10(3):e0118494.

3

Public Benefits of the Science to Achieve Results Program

The committee developed a framework to understand how the Environmental Protection Agency (EPA) Science to Achieve Results (STAR) program is designed to deliver its public benefits. The framework is summarized in a logic model. The logic-model approach is widely accepted for clarifying what programs must do to achieve their desired effects (Cozzens 1997; Engel-Cox et al. 2008; Liebow et al. 2009; Orians et al. 2009; McLaughlin and Jordan 2015). To develop its logic model, the committee considered one developed by an earlier National Research Council committee that evaluated EPA research efficiency (NRC 2008) and one used by the National Institute of Environmental Health Sciences (NIEHS) extramural research program (Engel-Cox et al. 2008).

The committee's logic model for STAR includes the standard categories: inputs, activities, outputs, outcomes, and impacts. Definitions of the logic-model components are as follows.

- **Inputs** are resources that feed into a program. These include process inputs, such as the allocated budget, the personnel assigned to administer it, and the procedures for selection and awarding of grants and fellowships. They also include such planning inputs as the strategic research action plans (StRAPs), and the knowledge obtained through research, scientific reviews, workshops, and published literature.
- **Activities** are the events or actions that take place. At the EPA, activities include the awarding of grants and fellowships, monitoring grantee activity, and engagement with funded researchers. At the grantee, activities include the conduct of research, developing infrastructure for data collection and analyses, mentoring of students, engaging with EPA and other stakeholders, and submitting annual and final project reports.
- **Outputs** are the products of the research activities. Outputs from the STAR program include knowledge outputs (publications, presentations, tools, and methods), infrastructure outputs (improved facilities for data collection and analysis), and workforce outputs (investigator career development and student career development).
- **Outcomes** are the benefits or changes that result from the use of the research outputs. Short-term outcomes include synthesis products and the next generation of scientists. Intermediate outcomes include outreach and communication to business and industry, government agencies (including other EPA offices), and a strengthened environmental-research community. Long-term outcomes include an improved body of knowledge, new program initiatives, public awareness, or new guidance, regulations, standards, or technologies.
- **Impacts** of STAR are forms of protection of human health and the environment. They can include improvement in environmental quality through strategies to protect the environment, increased sustainability, and improved health and healthy longevity (Bozeman 2003; Engel-Cox et al. 2008). Multiple interacting influences link STAR research to those impacts, but STAR research on its own does not produce them.

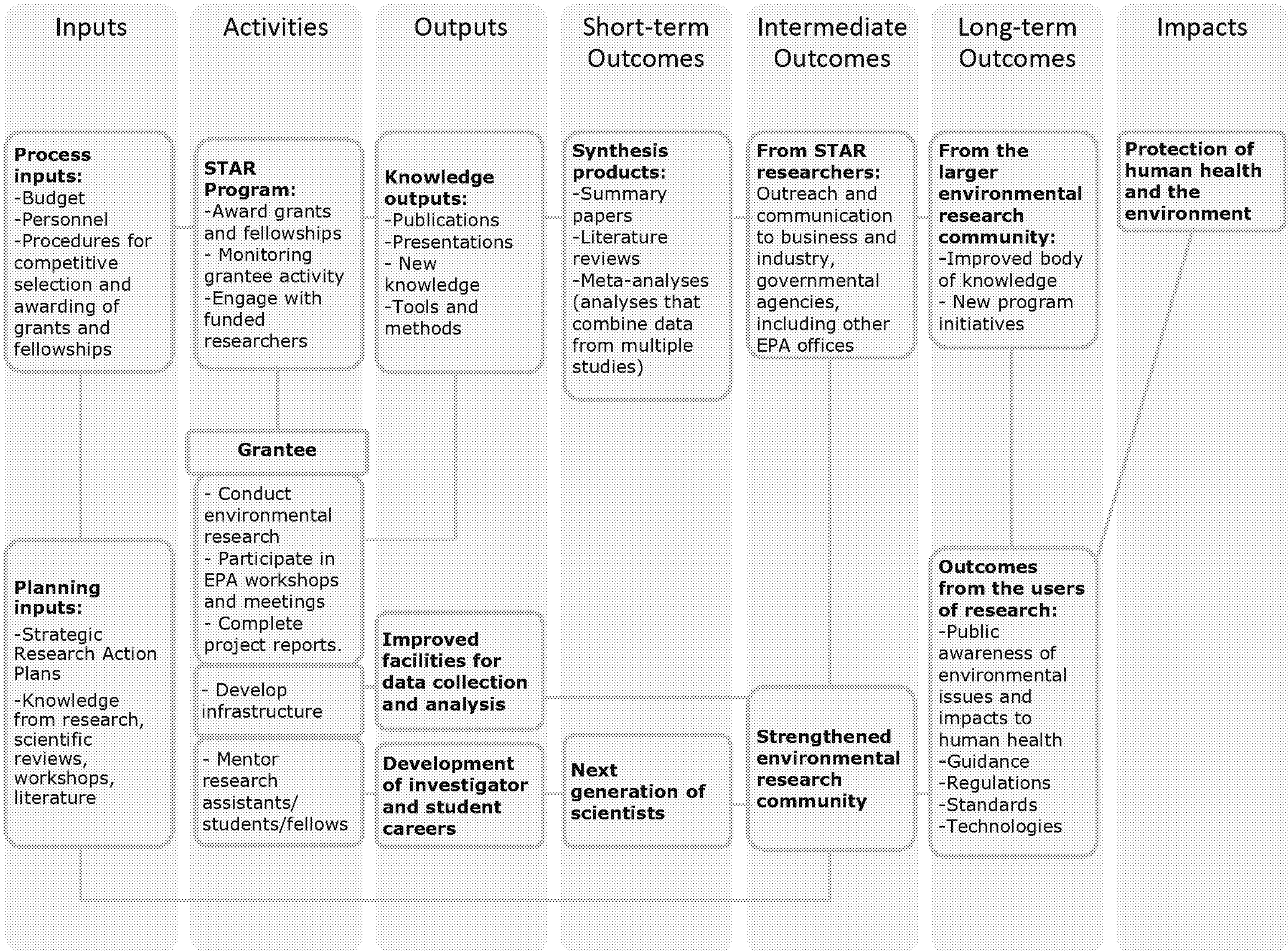

FIGURE 3-1 Logic model for the EPA STAR program. Lines represent linkages between the logic-model components. Source: Adapted from Engle-Cox et al. 2008; NRC 2008.

METRICS

Underlying the STAR logic model are specific metrics. Important input metrics of the STAR program include program budget (described in Chapter 1) and procedures (discussed in Chapter 2). Activity metrics include the number of grants and fellowships awarded per year and the number of requests for applications (RFAs) per year. From 2003 to 2015, STAR awarded 541 individual-investigator grants, 53 center grants, and 800 fellowships.

One metric of output is the number of publications. EPA reported that its internal grants database for October 2002-April 2017 contained 5,760 journal publications supported by STAR. That is probably an underestimate in that STAR grantees are required to report publications only until the grants are closed. The committee also reviewed other STAR publication information, a bibliometric analysis that EPA provided on the work of the Safe and Sustainable Water Resources (SSWR) program by STAR grantees, and one that the committee conducted by searching Google Scholar for "Science to Achieve Results EPA OR ORD" in December 2016. The committee chose Google Scholar because it is known to include more early publications and preprints than other databases, such as the Web of Science and Scopus (Meho and Kiduk 2007).

The information EPA provided on the SSWR STAR grantees revealed that grants resulted in over 900 publications from 165 grants issued in 1998-2016, including 844 journal articles, 49 books and book sections, and 25 conference papers and proceedings. Journal articles appeared in 273 journals that are indexed in the Web of Science Core Collection. EPA also used the Thomson Reuters Web of Science and InCites products to analyze the impact of STAR publications from the SSWR program. Half the grants analyzed had at least one publication with a percentile at or below 10% (D. Winner, EPA, Washington, DC, personal communication, 2016); that is, half the grants analyzed had at least one publication that was among the most highly cited publications in their field (a lower percentile means more citations) (Thompson Reuters 2014).

The committee's Google Scholar search yielded 71 papers published since 2000 that contained the key words and had been cited more than 100 times. The committee accessed those papers and checked their acknowledgments sections, and it confirmed that 63 resulted from research supported by STAR grants (46), fellowships (14), or a combination of grants and fellowships (three). It should be noted that such an evaluation would miss any paper that did not mention STAR in its acknowledgments or main text; this potentially reduced the number of STAR-funded papers found by the committee in that investigators might list only EPA grant numbers in the acknowledgments.

Other important output metrics considered by the committee are related to the scientific-community infrastructure. The program supports research projects nationwide. In FY 2014, the STAR program had grantees or fellows in all but two states, Vermont and South Dakota (Figure 3-2). Engagement with EPA in institutions around the United States has probably helped to create communities of scientists and engineers working in the human health and environmental sciences that would not have occurred without support from STAR grants and fellowships. Research grants also help to improve facilities for data collection and analysis within the supported grantees' institutions.

The proportion of STAR fellows that that become part of the larger scientific community is another important metric for STAR. The STAR fellowship program awarded 800 fellowships in 2003-2015. By reviewing the results of EPA's Fellowship Information Inventory (FII), a voluntary Web-based application system through which STAR fellows could choose to report career information, the committee assessed whether these scientists were continuing careers in environmental research. The FII was developed in 2003 for program-administration purposes, to collect student applications and supporting materials, and to provide a mechanism for fellows to submit information during and after their fellowships, including information on their research projects, publications, awards, and careers. The FII ended in 2011; while it was active (2003-2011), about 33% of the STAR fellows reported on their careers. The most commonly reported positions were postdoctoral positions (34%); these were followed by teaching positions (21%) and positions as researchers (16%), in the federal government (12%), in consulting firms (5%), in state,

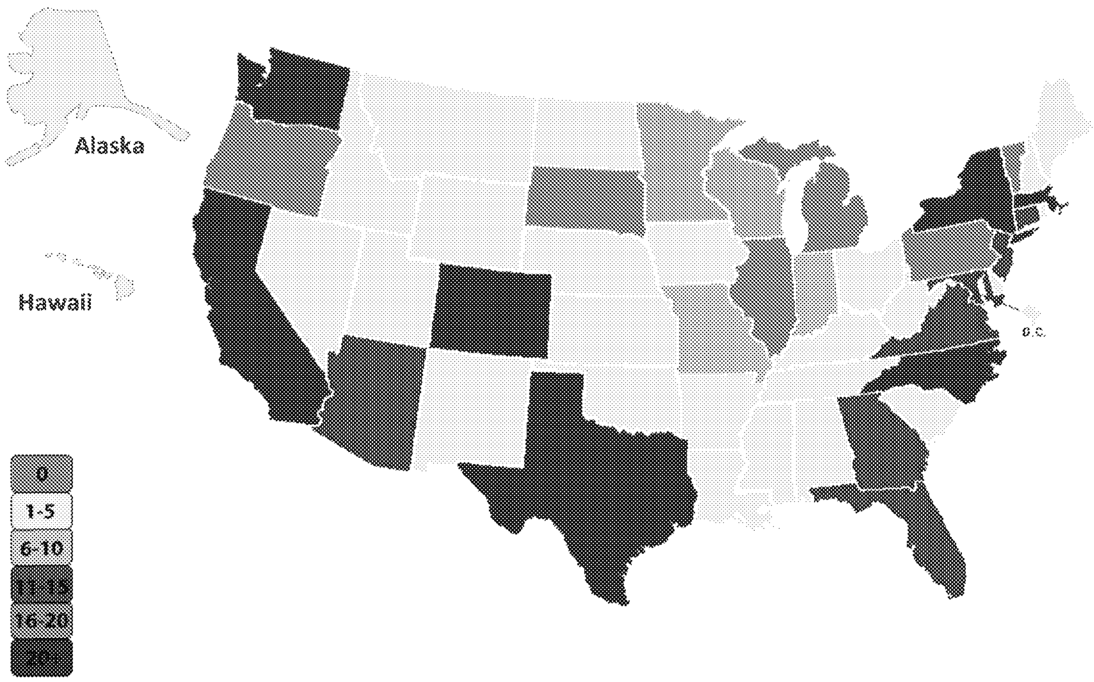

FIGURE 3-2 Geographic distribution of STAR grants, centers, and fellowships in FY 2014. Yellow indicates 1-5, green 6-10, purple 11-15, blue 16-20, and red over 20 active grantees in a state in 2014. In FY 2014, there were a total of 506 active STAR individual-investigator grants, centers, and fellowships. Source: Johnson 2016.

local, or tribal governments (4%), in private industry (4%), in nonprofits (3%), and in other appointments (1%) (D. Winner, EPA, Washington, DC, personal communication, 2016).

An example of a short-term outcomes produced by STAR are synthesis reports. For many of the center grants, STAR tasked principal investigators with producing synthesis reports, many of which have been published in the scientific literature (Savage and Diallo 2005; Fanning et al. 2009; Jacob and Winner 2009; Phenrat and Lowry 2009; Weaver et al. 2009; Breysse et al. 2013; Wagstrom et al. 2014).

An example of a long-term outcome, new program initiatives, can be assessed on the basis of the new ideas assessed in strategic planning documents. The StRAPs for the national programs Air, Climate, and Energy (ACE), Chemical Safety for Sustainability (CSS), SSWR, and Sustainable and Healthy Communities (SHC) all refer to priorities for STAR (EPA 2015a-d). In some cases, it is readily apparent that the new initiatives are informed by previous STAR initiatives. An illustration of that in the StRAP for the SHC program is the STAR priority initiative to create Environmental Health Disparities Centers, which will inform an environmental-justice roadmap in a way that is similar to how the EPA-NIEHS STAR Centers for Children's Environmental Health have been central to informing the Children's Environmental Health Roadmap.

An analysis provided by EPA that shows the types of organizations that are citing STAR research provides a metric of how STAR research is influencing the users of research results. In 2012, Scientific Consulting Group, an EPA contractor, identified 6,614 articles published in 2002-2012 that were funded by National Center for Environmental Research (NCER) grants. Using *Thomson Reuters Essential Science Indicators* and *Journal Citation Reports* as benchmarks, the contractor identified 252 of the 6,614 NCER articles as being in the top 1% of academic journal citations; thus, the papers had high impact and were among the most highly cited papers in their scientific fields. Another contractor, Science Applications International Corporation (SAIC), searched for citations of the 252 high-impact papers in nonacademic publications that are not indexed in bibliometric databases. It searched for such citations in three ways: using a data-mining tool that it developed to search the EPA Web sites, Google searches and manual review of results to identify regulatory and decision documents, and searches of select federal sources and documents, such as National Center for Environmental Assessment toxicology reviews and Agency for Toxic Substances and Disease Registry toxicology profiles. SAIC found that 105 of the 252 high-impact publications were cited in federal, state, or local government documents, in international guidelines, and in other documents of academic or nonprofit organizations, such as National Research Council reports and American Public Health Association guidelines (Information provided by EPA, Washington, DC, 2016).

The committee reviewed the 105 papers; all but one were supported by STAR grants. Table 3.1 shows the 10 papers that were cited most frequently in this analysis. Nine of them are focused on human health implications of air pollution; one describes a method of sampling to evaluate natural resources. The papers are also cited in a wide variety of documents, indicating that a wide variety of entities are using the results of STAR research.

The committee looked to see whether there were any trends among the types of grants that funded this research. The 105 publications came from 55 STAR grants. Table 3-2 provides the grant number, the number of papers cited in the 2012 analysis, the year awarded, and the abstract title for each grant that led to two or more of the cited papers. The most notable trend is the year in which a grant was awarded—all these grants were awarded at least 5 years before the impact could be observed. Another notable trend is that many of the grants were center grants, which have the important inputs of larger funding than individual-investigator grants but also often allow greater collaboration between institutions. The scientific topics that the grants cover are also of note. Many of the grants have a direct human-health focus—for example, the Southern California Particle Center and Supersite and the Center for the Study of Prevalent Neurotoxicants in Children —but others aim to understand how an emerging concern may affect health—for example, "Evaluating Nanoparticle Interactions with Skin". Other grants focused on environmental remediation, such as "Developing Functional Fe(0)-based Nanoparticles for In Situ Degradation of [Dense Non-Aqueous Phase Liquid] DNAPL Chlorinated Organic Solvents".

The committee also evaluated the STAR program's impact by developing a list of STAR research results that it considered beneficial to society on the basis of its own knowledge of the program. The committee found examples of STAR research that had had various types of benefits: reducing the costs of compliance with environmental regulations, providing a scientific basis for decisions required to protect public health and the environment, and improved methods for environmental management.

Some STAR research grants may lead to reductions in the cost of complying with environmental regulations. Such cost reductions could benefit regulated industries as well as states and localities that need to comply with environmental regulations. An example of STAR research that may benefit industry is the development of a tissue-based method for evaluating the thyroid effects of chemical exposures (Hutson et al. 2016). The method may reduce the cost of chemical testing compared with animal-based approaches. STAR research has also expanded the capability of air-pollution models by identifying key species and reactions occurring in cloud droplets that lead to PM formation. The improved models may reduce the costs of compliance with $PM_{2.5}$ national ambient air quality standards (NAAQSs) (Carlton et al. 2008). Yet another research project supported by STAR discovered a cost-effective method for removing nitrate from drinking water (Berquist et al. 2016).

STAR research has supported numerous public-health decisions. The STAR program implemented several large initiatives focused on the human health effects of air pollution, such as the Particulate Matter Centers, the Clean Air Research Centers, and the Air, Climate, and Energy Centers. Studies supported by those centers showed that increased air-pollution exposure leads to a decrease in life expectancy; examples include a followup of the Harvard Six Cities Study (Laden et al. 2006) and a large ecologic study of $PM_{2.5}$ exposure and mortality in 51 US cities (Pope et al. 2009). The findings supported earlier research and led to the development of a more protective $PM_{2.5}$ NAAQS (EPA 2006).

TABLE 3-1 Ten STAR papers with the Highest Numbers of Citations in Documents in EPA's 2012 Analysis

		No. Citations by Type of Documents					
Grant No.	Reference	*Federal Register*	Federal Government	State Government	Local Government	Private/ Nonprofit	Foreign
827351	Pope, C.A., R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287(9):1132-1141.	43	36	19	9	13	46
827353	Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. Reduction in fine particulate air pollution and mortality: Extended follow-up of the Harvard Six Cities study. Am. J. Respir. Crit. Care Med. 173(6):667-672.	25	23	2	8	10	10
829096	Stevens, D.L., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. J. Am. Stat. Assoc. 99(465):262-278.	0	25	16	3	8	3
827354	Oberdörster, G., E. Oberdörster, and J. Oberdörster. 2005. Nanotoxicology: An emerging discipline evolving from studies of ultrafine particles. Environ. Health Perspect. 113(7): 823-839.	1	8	4	1	5	35
827352; 831861	McConnell, R., K. Berhane, F. Gilliland, S.J. London, T. Islam, W.J. Gauderman, E. Avol, H.G. Margolis, and J.M. Peters. 2002. Asthma in exercising children exposed to ozone: A cohort study. Lancet 359(9304):386-391.	0	10	9	17	11	6
826708	McConnell, R., K. Berhane, L. Yao, M. Jerrett, F. Lurmann, F. Gilliland, N. Künzli, J. Gauderman, E. Avol, D. Thomas, and J. Peters. 2006. Traffic, susceptibility, and childhood asthma. Environ. Health Perspect. 114(5):766-772.	5	8	9	6	7	12
827351	Pope, C.A., R.T. Burnett, G. Thurston, M. Thun, E.E. Calle, D. Krewski, and J. Godleski. 2004. Cardiovascular mortality and long-term exposure to particulate air pollution. Circulation 109(1):71-77.	2	14	5	2	11	13
827354	Oberdörster G. 2001. Pulmonary effects of inhaled ultrafine particles. Int. Arch. Occup. Environ. Health 74(1):1-8.	0	6	4	5	2	29
827353	Peters, A., D.W. Dockery, J.E. Muller, and M.A. Mittleman. 2001. Increased particulate air pollution and the triggering of myocardial infarction. Circulation 103(23):2810-2815.	3	13	8	1	2	16
827352; 832413	Nel A. 2005. Air pollution-related illness: Effects of particles. Science 308(5723):804-806.	0	7	2	0	5	28
827352	Gauderman, W.J., H. Vora, R. McConnell, K. Berhane, F. Gilliland, D. Thomas, F. Lurmann, E. Avol, N. Kunzli, M. Jerrett, and J. Peters. 2007. Effect of exposure to traffic on lung development from 10 to 18 years of age: A cohort study. Lancet 369(9561):571-577.	0	6	1	8	14	11

TABLE 3-2 Summary of Grants That Led to Two or More Papers Found To Be Cited in Documents in EPA's 2012 Analysis

Grant No.	No. Papers Cited in Documents	Year Grant Awarded	Grant Abstract Title
826136	2	1997	Arsenicals, Glutathione Reductase and Cellular Redox Status
826139	2	1998	Studies of the Infectivity of Norwalk and Norwalk-like Viruses
827353	4	1999	Ambient Particle Health Effects: Exposure, Susceptibility, and Mechanisms
827351	3	1999	NYU-EPA PM Center: Health Risks of PM Components
827352	11	1999	Southern California Particle Center and Supersite (SCPCS)
827354	8	1999	Ultrafine Particles: Characterization, Health Effects and Pathophysiological Mechanisms
829389	2	2001	Center for the Study of Prevalent Neurotoxicants in Children
829436	2	2001	Study of Phthalates in Pregnant Woman and Children
829797	2	2002	Inflow, Chemistry and Deposition of Mercury to the West Coast of the United States
830959	2	2003	Application of a Unified Aerosol-Chemistry-Climate GCM to Understand the Effects of Changing Climate and Global Anthropogenic Emissions on U.S. Air Quality
831861	2	2003	Children's Environmental Health Center
830898	5	2003	Developing Functional Fe(0)-based Nanoparticles for In Situ Degradation of DNAPL Chlorinated Organic Solvents
831715	2	2004	Evaluating Nanoparticle Interactions with Skin
831725	2	2004	Metal Mixtures and Children's Health
832534	4	2005	Microbial Impacts of Engineered Nanoparticles
832415	2	2005	Rochester PM Center: Source-Specific Health Effects of Ultrafine/Fine Particles
832413	7	2005	Southern California Particle Center (SCPC)
833370	2	2007	Global Change and Air Pollution (GCAP) Phase 2: Implications for U.S. Air Quality and Mercury Deposition of Multiple Climate and Global Emission Scenarios for 2000-2050

Another large effective initiative is the Children's Environmental Health and Disease Prevention Research Centers, which aim to evaluate the effects of environmental exposures on child health and development. In 2016, a research project partially supported by a STAR grant recognized that infants could be exposed to arsenic through rice cereal (Karagas et al. 2016); this discovery led the Food and Drug Administration to propose regulations to protect infant health (FDA 2016). Another example is the discovery by investigators at the University of Washington Children's Center that farmworker children had increased exposure to the pesticide ingredient azinphos-methyl (Curl et al. 2002); this informed EPA's decision to phase out the use of azinphos-methyl in pesticides (EPA 2006).

Examples of STAR research to improve environmental management include experiments in market-based incentives to lower emissions and studies of the potential reduction in the cost of pollution abatement (Anton et al. 2004) and auctions in which landowners and sellers compete to obtain part of a fixed budget allocated by the regulator to subsidize pollution abatement (Cason and Gangadharan 2004).

Those examples and others listed in Table 3-3 show how STAR results are contributing to a knowledge base that benefits society by improving human health and the environment.

COMMITTEE'S EVALUATION

Identifying the public benefits of the STAR program is challenging. Part of the difficulty arises from the length of time that it takes for a grant award to yield a public-health benefit; often, the benefit is a calculated or modeled benefit rather than a measured change in a health or environmental outcome. In addition, as a grant is traced through the logic model, its influence becomes more diffuse as the knowledge gained from one grant is synthesized with other information to yield public benefits. The information provided by EPA that describes the frequency of STAR citations in decision documents indicates STAR's ability to effect public benefits. There are some flaws in the analysis, for example it is 5 years old, so there likely more than 252 high impact publications now that EPA could search for citations in decision documents. In addition, a mere citation in a decision document does not necessarily mean that the paper drove the decision; a cited paper might have been merely critiqued within the citing document. Nonetheless, in light of the examples presented in this chapter, it is evident that the STAR program has had important implications for human health and environmental protection.

TABLE 3-3 Selected Examples of STAR Research Findings and the Public Benefits to Which They Contributed

Environmental Program	Research Findings	Public Benefits
ACE	$PM_{2.5}$ exposures lead to cardiovascular effects and are linked with hospital admissions and premature death (Pope et al. 2009); mortality is decreased by reducing exposure (Laden et al. 2006)	Lowering $PM_{2.5}$ national ambient air quality standard from 15 to 12 μg/m^3 (EPA 2012)
	No association found between coarse particles ($PM_{2.5\text{-}10}$) and hospital admissions for cardiovascular and respiratory diseases (Peng et al. 2008).	Coarse PM indicator not changed (EPA 2012)
	Improved chemical and physical representations in air-quality models (Carlton et al. 2008)	Potential for more effective and lower-cost state implementation plans to attain PM national ambient air quality standards
	Black carbon from diesel-fueled vehicles contributes to climate change (Bond et al. 2013)	Recognition that existing diesel-emission controls may provide major climate benefits in addition to air-quality benefits (National Academies of Sciences, Engineering and Medicine 2016)
	Climate change can worsen air quality (Jacob and Winner 2009)	Greenhouse-gas reductions are likely to provide air-quality improvements (IPCC 2014)
CSS	Organotypic culture models can expedite toxicity testing (Hutson et al. 2016)	Expected to lead to less expensive chemical safety testing methods
SSWR	Demonstration of an improved method for removing nitrogen during drinking-water treatment (Bergquist et al. 2016)	May lead to a method to treat drinking water in areas where nitrate contamination of source water is a concern
	Development of methods to use surrogates to study fate and transport of pathogens in environment (Sinclair et al. 2012)	Improvements in modeling of microbial threats in water reuse (Zimmerman et al. 2016)
SHC	Higher childhood asthma rates may be due to air pollution from trucks and residential heating oil (Patel et al. 2009)	California required particle filters on diesel trucks (CARB 2014); New York City mandated cleaner heating oil (NYC DEP 2011)
	Rice and brown rice syrup can contain high concentrations of toxic inorganic arsenic (Karagas et al. 2016)	Food and Drug Administration proposed a limit for inorganic arsenic in infant rice cereal (FDA 2016)
	Great Lakes tribal children consuming large walleye are at greatest risk associated with methyl mercury (Foran et al. 2010)	Fish-consumption guidelines developed for high-risk and sensitive populations (GLIFWC 2016)
	Farmworker childrend had increased exposure to azinphos-methyl (Curl et al. 2002)	EPA phased out use of azinphos-methyl (EPA 2006)
	Design of auctions for land-management changes may affect market performance (Cason and Gangadharan 2004)	Improved designs in auctions for pollution abatement (Hellerstein et al 2015)
	Businesses are adopting environmental-management systems voluntarily (Anton et al. 2004)	Design of market-based approaches for environmental management (Rennings et al. 2006).

Through the funding of research institutions throughout the United States, STAR adds to communities of science and generates reservoirs of environmental-research knowledge. Those reservoirs of knowledge represent the accumulation of understanding, knowledge, and previous research in environmental sciences and greatly contribute to the research environment. Such a "knowledge pool" encompasses both research and the collaboration of people who "interact and produce innovation and discovery through unpredictable paths and at uneven intervals" (Cozzens 1997).

The STAR fellowship program added to the knowledge community. It encouraged promising young scientists to obtain advanced degrees and pursue careers in environment-related fields. In addition, the committee found that almost 30% of the papers identified in Google Scholar as having been cited more than 100 times acknowledged support by a STAR fellowship; this suggests that these young investigators are doing high-quality work. With regard to building a research community, a major output is students trained in the methods of the research field and in analysis of complex data; these young investigators learn to thrive in interdisciplinary environments in which complex problems are tackled. The data collected by EPA through the FII show that many of the STAR fellows remained in academic or other research institutions, although the data are incomplete because of the low rate of response by former fellows and the lack of detail in the data collection. Some universities have begun to track career outcomes of students supported by extramural grants by using internal employment records (Weinberg et al. 2014). EPA should consider investing in similar approaches and including past and present STAR fellowship holders in its analysis.

STAR has made progress in communicating findings of its programs by requiring synthesis documents from center investigators, but this approach has been inconsistent, and the committee urges EPA to invest more heavily in it.

Concrete effects of results of individual grants on health and the environment are usually difficult to characterize quantitatively; thus, the National Institutes of Health (NIH) evaluation process, for example, is actively seeking approaches to demonstrate how NIH research findings can be linked quantitatively to improvements in health outcomes (NIH 2014). Often, the links between research studies and benefits to human health are described best in case studies, which are therefore a valuable way of communicating the favorable effects of action-relevant research of the sort that the STAR program supports.

CONCLUSIONS

EPA has created a vehicle that fosters collaboration and knowledge-sharing and has produced research that contributes to public benefits. EPA should consider reporting the stories of STAR's benefits more prominently on its Web site and blogs. It should also consider requiring grantees to report the potential influence and public benefits of their awards as part of the grantee final report and even 5-10 years after their research has been completed. However, tracking the benefits remains challenging for many organizations that support or conduct research. Evaluations like the present one would be improved if there were more robust electronic databases that could be easily searched to detect linkages between grants, fellowships, and public benefits. Through collaboration with other organizations, EPA could make strides in this regard. There is a substantial effort throughout the federal government to mine data in reports, literature, administrative records, and so forth to identify intermediate outcomes more effectively, to link federally funded projects to long-term impacts, and to track career outcomes of graduate students supported by fellowships or graduate research assistantships. NIH, for example, has created the High Impacts Tracking System. The system loads progress reports and program officers' notes about grants into a searchable system and allows structured tagging of outputs and impacts. Another NIH example is RePARS, which allows automatic retrieval of NIH funding sources for publications in any list, such as the bibliography of a National Academies report (Drew et al. 2016). NIH recently used its new systems to show the impact of the National Toxicology Program with hexavalent chromium as a case study (Xie et al. 2016). EPA should devote personnel time to such efforts and apply the techniques to construct richer and more robust indicators to demonstrate how the results of STAR grants have improved human health and the environment.

REFERENCES

Anton, W.R.Q, G. Deltas, and M. Khanna. 2004. Incentives for environmental self-regulation and implications for environmental performance. J. Environ. Econom. Manage. 48(1):632-654.

Bergquist, A.M., J.K. Choe, T.J. Strathmann, and C.J Werth. 2016. Evaluation of a hybrid ion exchange-catalyst treatment technology for nitrate removal from drinking water. Water Res. 96(1):177-187.

Bond, T. C., S.J. Doherty, D.W. Fahey, P.M. Forster, T. Berntsen, B.J. DeAngelo, M.G. Flanner, S. Ghan, B. Kärcher, D. Koch, S. Kinne, Y. Kondo, P.K. Quinn, M.C. Sarofim, M.G. Schultz, M. Schulz, C. Venkataraman, H. Zhang, S. Zhang, N. Bellouin, S.K. Guttikunda, P.K. Hopke, M.Z. Jacobson, J.W. Kaiser, Z. Klimont, U. Lohmann, J.P. Schwarz, D. Shindell, T. Storelvmo, S.G. Warren, and C.S. Zender. 2013. Bounding the role of black carbon in the climate system: A scientific assessment. J. Geophys. Res. Atmos. 118(11): 5380-5552.

Bozeman, B. 2003. Public value mapping of science outcomes: Theory and method. Pp. 3-48 in Knowledge Flows and Knowledge Collectives: Understanding the Role of Science and Technology Policies in Development, Vol. 2. Public Value Mapping for Scientific Research, B. Bozeman, D. Sarewitz, S. Feinson, G. Foladori, M. Gaughan, A. Gopta,B. Sampat, and G. Zachary, eds. Washington, DC: Center for Science Policy and Outcomes.

Breysse, P.N., R.J. Delfino, F. Dominici, A.C.P. Elder, M.W. Frampton, J.R. Froines, A.S. Geyh, J.J. Godleski, D.R. Gold, P.K. Hopke, P. Koutrakis, N. Li, G. Oberdörster, K.E. Pinkerton, J.M. Samet, M.J. Utell, and A.S. Wexler. 2013. U.S. EPA particulate matter research centers: Summary of research results for 2005-2011. Air Qual. Atmos. Health 6(2):333-355.

CARB (California Air Resources Board). 2014. Multi-Regulation Summary (MRS) Requirements for Diesel Truck and Equipment Owners [online]. Available: https://www.arb.ca.gov/msprog/onrdiesel/documents/multirule.pdf [accessed April 27, 2017].

Carlton, A.G., B.J. Turpin, K.E. Altieri, S.P. Seitzinger, R. Mathur, S.J. Roselle, and R.J. Weber. 2008. CMAQ model performance enhanced when in-cloud secondary organic aerosol is included: Comparisons of organic carbon predictions with measurements. Environ. Sci. Technol. 42 (23):8798-8802.

Cason, T.N., and L. Gangadharan. 2004. Auction design for voluntary conservation programs. Am. J. Agricult. Econ. 86 (5):1211-1217.

Cozzens, S.E. 1997. The knowledge pool: Measurement challenges in evaluating fundamental research programs. Eval. Program Plann. 20(1):77-89.

Curl, C.L., R.A. Fenske, J.C. Kissel, J.H. Shirai, T.F. Moate, W. Griffith, G. Coronado, and B. Thompson. 2002. Evaluation of take-home organophosphorus pesticide exposure among agricultural workers and their children. Environ. Health Perspect. 110(12):A787-A792.

Drew, C.H., K.G. Pettibone, F.O. Finch III, D. Giles, and P. Jordan. 2016. Automated research impact assessment: A new bibliometrics approach. Scientometrics 106(3):987-1005.

Engel-Cox, J.A., B. Van Houten, J. Phelps, and S.W. Rose. 2008. Conceptual model of comprehensive research metrics for improved human health and environment. Environ. Health Perspect. 116 (5):583-592.

EPA (U.S. Environmental Protection Agency). 2006. Interim Reregistration Eligibility Decision for Azinphos-Methyl, Case No. 0235. Office of Pesticide Protection, Washington, DC [online]. Available: https://archive.epa.gov/pesticides/reregistration/web/pdf/azinphosmethyl_ired.pdf [accessed April 27, 2017].

EPA. 2012. Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. EPA/600/R-12/056F. National Center of Environmental Assessment RTP Division, Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC [online]. Available: https://www3.epa.gov/ttn/naaqs/standards/pm/data/20121213psa.pdf [accessed April 27, 2017].

EPA. 2015a. Air, Climate, and Energy Strategic Action Plan 2016-2019. EPA 601/K-15/005. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC [online]. Available: https://www.epa.gov/sites/production/files/2015-10/documents/strap_2016_ace_508.pdf [accessed January 17, 2017].

EPA. 2015b. Chemical Safety for Sustainability Strategic Research Action Plan 2016-2019. EPA 601/K-15/003. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC [online]. Available: https://www.epa.gov/sites/production/files/2016-02/documents/strap_2016_css_508_compliant_final_optimized_0.pdf [accessed January 17, 2017].

EPA. 2015c. Safe and Sustainable Water Resources Strategic Research Action Plan 2016-2019. EPA 601/K-15/004. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC [online]. Available: https://www.epa.gov/sites/production/files/2015-10/documents/strap_2016_sswr_508.pdf [accessed January 17, 2017].

EPA. 2015d. Sustainable and Healthy Communities Strategic Research Action Plan 2016-2019. EPA 601/K-15/006. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC [online]. Available: https://www.epa.gov/sites/production/files/2015-10/documents/strap_2016_shc_508.pdf [accessed January 17, 2017].

Fanning, E.W., J.R. Froines, M.J. Utell, M. Lippmann, G. Oberdörster, M. Frampton, J. Godleski, and T.V. Larson. 2009. Particulate matter (PM) research centers (1999-2005) and the role of interdisciplinary center-based research. Environmental Health Perspect. 117(2):167-174.

FDA (U.S. Food and Drug Administration). 2016. FDA proposes limit for inorganic arsenic in infant rice cereal. FDA News Release, April 1, 2016 [online]. Available: https://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm493740.htm [accessed May 17, 2017].

Foran, J.A., A.D. DeWeese, M.J. Hudson, and N.E. Kmiecik. 2010. Evaluation of mercury exposure reduction through a fish consumption advisory program for anishinaabe tribal members in northern Wisconsin, Michigan, and Minnesota. J. Environ. Public Health 2010:802584.

Gauderman, W.J., H. Vora, R. McConnell, K. Berhane, F. Gilliland, D. Thomas, F. Lurmann, E. Avol, N. Kunzli, M. Jerrett, and J. Peters. 2007. Effect of exposure to traffic on lung development from 10 to 18 years of age: A cohort study. Lancet 369(9561):571-577.

GLIFWC (Great Lakes Indian Fish and Wildlife Commission). 2016. Mercury-Based Consumption Advice for Ceded Territory Muskellunge. Memo from Sara Moses, Environmental Biologist, to Neil Kmiecik, Biological Services Director, Great Lakes Indian Fish and Wildlife Commission, Odanah, WI, February 8, 2016 [online]. Available: https://www.glifwc.org/Mercury/Musky%20Consumption%20Advice%20Memo%20Feb2016.pdf [accessed April 27, 2017].

Hellerstein, D., N. Higgins, and M. Robers. 2015. Options for Improving Conservation Programs: Insights From Auction Theory and Economic Experiments. Economic Research Service Report No. 181. U.S. Department of Agriculture, Economic Research Service, Washington, DC. January 2015. [online]. Available: https://www.ers.usda.gov/webdocs/publications/45333/50532_err181.pdf?v=42502 [accessed April 27, 2017].

Hutson, M.S., P.G. Alexander, V. Allwardt, D.M Aronoff, K.L. Bruner-Tran, D.E. Cliffel, J.M. Davidson, A. Gough, D.A. Markov, L.J. McCawley, J.R. McKenzie, J.A. McLean, K.G. Osteen, V. Pensabene, P.C. Samson, N.K. Senutovitch, S.D. Sherrod, M.S. Shotwell, D.L. Taylor, L.M. Tetz, R.S. Tuan, L.A. Vernetti, and J.P. Wikswo. 2016. Organs-on-chips as bridges for predictive yoxicology. Appl. In Vitro Toxicol. 2(2):97-102.

IPCC (Intergovernmental Panel on Climate Change). 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A. Global and Sectoral Aspects, C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White, eds. Cambridge, UK: Cambridge University Press. 1132 pp.

Jacob, D.J., and D.A. Winner. 2009. Effect of climate change on air quality. Atmos. Environ. 43 (1):51-63.

Johnson, J. 2016. Presentation at the First Meeting on Review of EPA's Science to Achieve Results' Research Grants Program, June 21, 2016, Washington, DC.

Karagas, M.R., T. Punshon, V. Sayarath, B.P. Jackson, C.L. Folt, and K.L. Cottingham. 2016. Association of rice and rice-product consumption with arsenic exposure early in life. JAMA Pediatr. 170(6):609-616.

Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. Reduction in fine particulate air pollution and mortality: Extended follow-up of the Harvard Six Cities study. Am. J. Respir. Crit. Care Med. 173(6):667-672.

Liebow, E., J. Phelps, B. Van Houten, S. Rose, C. Orians, J. Cohen, P. Monroe, and C.H. Drew. 2009. Toward the assessment of scientific and public health impacts of the National Institute of Environmental Health Sciences Extramural Asthma Research Program using available data. Environ. Health Perspect. 117(7):1147-1154.

McConnell, R., K. Berhane, F. Gilliland, S.J. London, T. Islam, W.J. Gauderman, E. Avol, H.G. Margolis, and J.M. Peters. 2002. Asthma in exercising children exposed to ozone: A cohort study. Lancet 359(9304):386-391.

McConnell, R., K. Berhane, L. Yao, M. Jerrett, F. Lurmann, F. Gilliland, N. Künzli, J. Gauderman, E. Avol, D. Thomas, and J. Peters. 2006. Traffic, susceptibility, and childhood asthma. Environ. Health Perspect. 114(5):766-772.

McLaughlin, J.A., and G.B. Jordan. 2015. Using logic models. Pp. 62-87 in Handbook of Practical Program Evaluation, 4th Ed., K.E. Newcomer, H.P. Hatry, and J.S. Wholey, eds. Hoboken, NJ: John Wiley & Sons, Inc.

Meho, L.I., and Y. Kiduk. 2007. Impact of data sources on citation counts and rankings of LIS faculty: Web of Science versus Scopus and Google Scholar. J. Am. Soc. Inf. Sci. Technol. 58(13):2105-2125.

National Academies of Sciences, Engineering, and Medicine. 2016. The Future of Atmospheric Chemistry Research: Remembering Yesterday, Understanding Today, Anticipating Tomorrow. Washington, DC: The National Academies Press.

Nel, A. 2005. Air pollution-related illness: Effects of particles. Science 308(5723):804-806.

NIH (National Institute of Health). 2014. Scientific Management Review Board Report on Approaches to Assess the Value of Biomedical Research Supported by NIH [online]. Available: https://smrb.od.nih.gov/documents/reports/VOBR%20SMRB_Report_2014.pdf [accessed May 17, 2017].

NRC (National Research Council). 2008. Evaluating Research Efficiency in the U.S. Environmental Protection Agency. Washington, DC: The National Academies Press.

NYC DEP (New York City Department fof Environmental Protection). 2011. Promulgation of Amendments to Chapter 2 of Title 15 of the Rules of the City of New York Rules Governing the Emissions from the Use of #4 and #6 Fuel Oil in Heat and Hot Water Boilers and Burners [online]. Available: http://www.nyc.gov/html/dep/pdf/air/heating_oil_rule.pdf [accessed April 27, 2017].

Oberdörster, G. 2001. Pulmonary effects of inhaled ultrafine particles. Int. Arch. Occup. Environ. Health 74(1):1-8.

Oberdörster, G., E. Oberdörster, and J. Oberdörster. 2005. Nanotoxicology: An emerging discipline evolving from studies of ultrafine particles. Environ. Health Perspect. 113(7): 823-839.

Orians, C., J. Abed, C. Drew, S.W. Rose, J. Cohen, and J. Phelps. 2009. Scientific and public health impacts of the NIEHS Extramural Asthma Research Program- insights from primary data. Res. Eval. 18(5):375-385.

Patel, M.M., L. Hoepner, R. Garfinkel, S. Chillrud, A. Reyes, J.W. Quinn, F. Perera, and R.L. Miller. 2009. Ambient metals, elemental carbon, and wheeze and cough in New York City children through 24 months of age. Am. J. Respir. Crit. Care Med. 180(11):1107-1113.

Peng, R.D., H.H. Chang, M.L. Bell, A. McDermott, S.L. Zeger, J.M. Samet, and F. Dominici. 2008. Coarse particulate matter air pollution and hospital admissions for cardiovascular and respiratory diseases among Medicare patients. JAMA 299(18):2172-2179.

Peters, A., D.W. Dockery, J.E. Muller, and M.A. Mittleman. 2001. Increased particulate air pollution and the triggering of myocardial infarction. Circulation 103(23):2810-2815.

Phenrat, T., and G.V. Lowry. 2009. Physicochemistry of polyelectrolyte coatings that increase stability, mobility, and contaminant specificity of reactive nanoparticles used for groundwater remediation. Pp. 249-267 in Nanotechnology Applications for Clean Water, N. Savage, M. Diallo, J. Duncan, A. Street, and R. Sustich, eds. Norwich, NY: William Andrew Inc.

Pope, C.A., R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287(9):1132-1141.

Pope, C.A., R.T. Burnett, G. Thurston, M. Thun, E.E. Calle, D. Krewski, and J. Godleski. 2004. Cardiovascular mortality and long-term exposure to particulate air pollution. Circulation 109(1):71-77.

Pope, C.A., M. Ezzati, and D.W. Dockery. 2009. Fine-particulate air pollution and life expectancy in the United States. N. Engl. J. Med. 360(4):376-386.

Rennings, K., A. Ziegler, K. Ankele, and E. Hoffmann. 2006. The influence of different characteristics of the EU environmental management and auditing scheme on technical environmental innovations and economic performance. Ecol. Econ. 57(1):45-59.

Savage, Nora, and Mamadou S. Diallo. 2005. Nanomaterials and water purification: opportunities and challenges. J. Nanopart. Res. 7(4):331-342.

Sinclair, R.G., J.B. Rose, S.A. Hashsham, C.P. Gerba, and C.N. Haas. 2012. Criteria for selection of surrogates used to study the fate and control of pathogens in the environment. Appl. Environ. Microbiol. 78 (6):1969-1977.

Stevens, D.L., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. J. Am. Stat. Assoc. 99(465):262-278.

Thomson Reuters. 2014. InCities Essential Science Indicators Help [online]. Available: http://ipscience-help.thomsonreuters.com/incitesLiveESI/ESIGroup/fieldBaselines/PercentilesBaselines.html [accessed April 27, 2017].

Hellerstein, D., N. Higgins, and M. Robers. 2015. Options for Improving Conservation Programs: Insights From Auction Theory and Economic Experiments. Economic Research Service Report No. 181. U.S. Department of Agriculture, Economic Research Service, Washington, DC. January 2015. [online]. Available: https://www.ers.usda.gov/webdocs/publications/45333/50532_err181.pdf?v=42502 [accessed April 27, 2017].

Johnson, J. 2016. Presentation at the First Meeting on Review of EPA's Science to Achieve Results' Research Grants Program, June 21, 2016, Washington, DC.

Wagstrom, K.M., K.R. Baker, A.E. Leinbach, and S.W. Hunt. Synthesizing scientific progress: Outcomes from U.S. EPA's Carbonaceous Aerosols and Source Apportionment STAR Grants. Environ. Sci. Technol. 48(18):10561-10570.

Weinberg, B.A., J. Owen-Smith, R.F. Rosen, L. Schwarz, B. McFadden Allen, R.E. Weiss, and J. Lane. 2014. Science funding and short-term economic activity. Science. 344(6179):41-43.

Weaver, C.P., E. Cooter, R. Gilliam, A. Gilliland, A. Grambsch, D. Grano, B. Hemming, S.W. Hunt, C. Nolte, D.A. Winner, and X.Z. Liang. 2009. A preliminary synthesis of modeled climate change impacts on US regional ozone concentrations. Bull. Am. Meteorol. Soc. 90(12):1843.

Xie, Y., S. Holmgren, D.M.K. Andrews, and M.S. Wolfe. 2017. Evaluating the impact of the US National Toxicology Program: A case study on hexavalent chromium. Environ. Health Perspect. 125(2):181-188.

Zimmerman, B.D., A. Korajkic, N.E. Brinkman, A.C. Grimm, N.J. Ashbolt, and J.L. Garland. 2016. A spike cocktail approach to improve microbial performance monitoring for water reuse. Water Environ. Res. 88(9): 824-837.

4

Research for Addressing the Environmental Protection Agency's Priority Scientific Questions

Environmental research has led to technologic advances and improved policies that have resulted in enormous improvements in environmental quality and public health which may have saved lives and reduced healthcare costs nationwide. However, many complex environmental challenges remain, and new ones are emerging that are associated with interacting technologic, sociologic and economic factors, including changes in energy production and use, development of new chemicals and nanomaterials, geographic shifts in the US population, the growth of metropolitan areas, and demands for affordable agricultural products.

Major research challenges involve understanding the potential responses of environmental systems and effects on public health that might occur on various spatial scales (from local to global) and temporal scales (from acute to chronic). Stemming from discussions presented in Burke et al. (2017) and NRC (2012a, 2013a), examples of environmental research challenges include:

- How would the wide-scale use of new energy options and emerging technologies affect water availability and quality, land use patterns, and air quality?
- How would ecosystems services (for example, buffering against coastal storms and pollinating food-bearing plants) be affected by habitat losses resulting from supplying the resource demands of a dynamic population?
- How would changes in biogeochemical cycles resulting from agricultural nutrient runoff affect aquatic ecosystems and human well-being?
- How could adverse health effects from exposure to hazardous chemicals and other materials be avoided through safe product design and appropriate consumer use?
- What societal abilities are needed to respond quickly to address environmental consequences of disasters arising from natural events (such as storms), accidents at major industrial facilities (such, mines and wells), and terrorism events?

Does the Science to Achieve Results (STAR) program contribute to shedding light on those problems? The discussion of the STAR program's public benefits in Chapter 3 suggests that it can, but could the program have been doing more? To answer that question, the committee first considered what scientific disciplines are needed to produce knowledge for addressing important scientific issues related to protecting human health and the environment. The disciplines include the more basic subjects—such as the earth sciences, atmospheric sciences, life sciences, ecology, and toxicology—and the more applied domains, such as environmental engineering, sustainable energy, human exposure and health effects, and human behavioral studies.

Figure 4-1 provides a layered view of the contributing fields of knowledge, from basic research along the bottom row (in yellow) to the kinds of scientific considerations that are integrated into environmental management, public policy, and decision-making, including considerations such as innovative technologies, innovative strategies for risk management, and innovative approaches to communication and citizen participation along the top row (in green). As suggested by the arrow on the left in Figure 4-1, knowledge from the fundamental domains is adapted and refined as it moves upward to practical application, building environmental science capacity. Similarly, knowledge gaps and research needs identified in the applied fields inform and motivate new directions in fundamental research, as suggested by the arrow on the right.

The committee found that STAR has supported almost all of these disciplines. The subjects of requests for applications (RFAs) were in almost every discipline with the exception of those in the bottom row (Appendix C). Human exposure and health effects, toxicology, risk analysis, innovative risk management, and systems modeling and decision support were some of the fields most commonly represented by the RFAs. The committee also noted that the RFA topics were highly interdisciplinary and few fell neatly into a single category. Examples of subjects in RFAs that arguably fell into a single field were valuation for environmental policy, case studies and experimental testbeds in environmental economics (environmental trading programs and methodologic advances in benefit-transfer methods), the development of environmental health outcome indicators, and sources and atmospheric formation of organic particulate matter (Appendix C).

STAR-supported research also contributed to a wide variety of these fields. The committee categorized the papers that it identified as having been cited more than 100 times in Google Scholar according to the fields of knowledge in Figure 4-1 (Appendix D). The papers extended across a wide spectrum of basic to applied fields needed for the generation and application of environmental knowledge; only the field of earth sciences was not covered. Some of the most common fields addressed by the papers were ecology, atmospheric sciences, climate sciences, human exposure and health effects, risk analysis, systems modeling and decision support, environmental economics, environmental engineering, and innovative risk management. The results of the categorization of papers identified funding in fields that often provided a clear pathway toward protecting human health and the environment—including the development of innovative technology (for example, Lee and Sigmund 2003; Cao et al. 2005; Karnik et al. 2005), innovative methods for risk management (for example, Salzman et al. 2001; Cason and Gangadharan 2004; Weber and Matthews 2008; Plevin et al. 2010), and innovative methods for communication and public participation (for example, Anton et al. 2004; Gunningham, et al. 2005; Teisl et al. 2008).

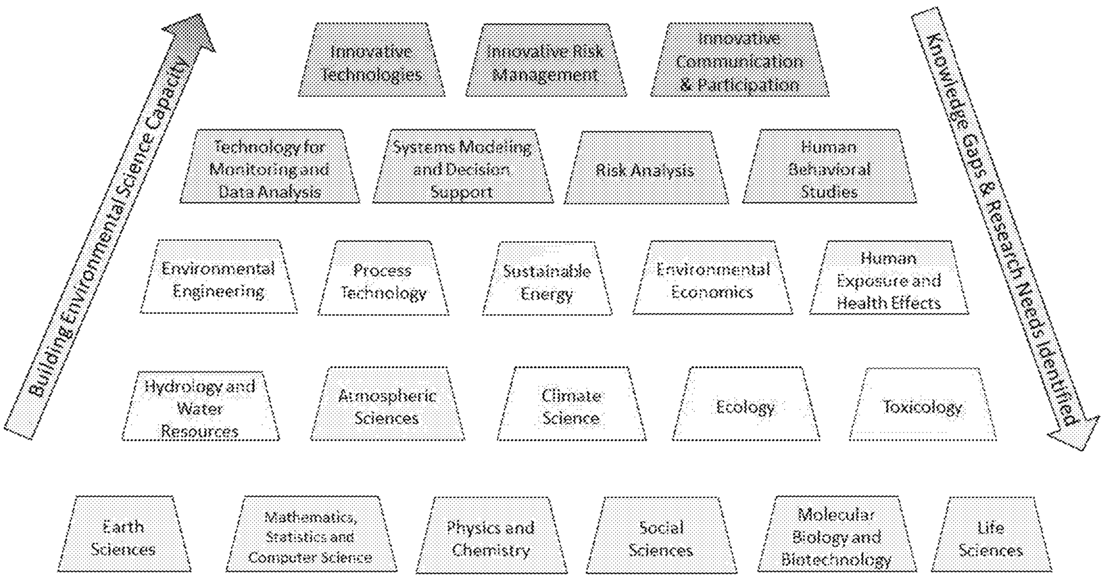

FIGURE 4-1 The diverse aspects of basic and applied science and technology that support scientifically informed environmental management and public policy. Source: Adapted from McDaniels and Small 2004.

A Review of The Environmental Protection Agency's Science to Achieve Results Research Program

DISTINCTIVE NATURE OF SCIENCE TO ACHIEVE RESULTS RESEARCH

The committee found that STAR's distinguishing characteristics lie not in the research topic areas that it supports, but that the program is used strategically by EPA to address critical gaps in knowledge related to human and ecosystem health issues. This strategic focus is important because the challenges associated with environmental protection comprise many interacting factors, on various spatial and temporal scales, often characterized by being difficult to define, and socially complex (NRC 2012a). Therefore addressing those challenges requires multi-disciplinary research that strives to understand social, economic, and environmental drivers that inform the approaches needed to devise optimal solutions. STAR has been distinctively targeted on these research needs.

Two major STAR supported efforts that have been used by EPA to address critical knowledge gaps are the various Air Research Centers (Box 4-1) and the Children's Environmental Health and Disease Prevention Research Centers (Box 4-2). Both of these research endeavors began in response to a critical research need having been identified by Congress or Federal Executive Order and have evolved over time as a result of the changing understanding of these topic areas. For example, the Air Research Centers began with looking at the health effects of exposure to airborne particulate matter, then expanded to evaluating exposure-response relationships to different concentrations of particulate matter, multi-pollutant interaction (such as particulate matter and gaseous pollutants), and are now looking at the influence of broad factors on local air quality and health. The Children's Environmental Health and Disease Prevention Research Centers began with examining at the influence of the chemical-physical environment on asthma and neurodevelopment, but over time many of the centers investigated new questions about possible relationships between environmental factors and other health outcomes such as obesity (NIEHS/EPA 2013). The flexibility of the STAR program allowed EPA to address these critical research gaps.

BOX 4-1 Air Research Centers

1999 – Particulate Matter Research Centers. This effort was created in response to National Research Council's "Research Priorities for Airborne Particulate Matter" which was conducted at the request of Congress (NRC 1998). These centers advanced the understanding of how PM health effects occur, which constituents or properties of PM are most responsible, and which populations are the most vulnerable (Fanning et al. 2003). This research greatly contributed to the 2006 and 2012 $PM_{2.5}$ National Ambient Air Quality Standard reviews (see Table 3-1, Table 3-2).

2005 – Particulate Matter Research Centers. The research conducted by the 2005 centers built upon and expanded on the previous effort. Major findings from this effort linked susceptibility, mechanisms of health effects, exposure-response relationships, and emissions sources (Breysse et al. 2013).

2010 – Clean Air Research Centers. These centers addressed knowledge gaps that were becoming identified regarding the health effects of multi-pollutant interactions. Major findings from this effort are improved understanding of the impacts of exposure to pollution from roadways, of impacts varying across life stages and beyond cardiovascular health endpoints, and of susceptibility and interaction with metabolic disorders (EPA 2016).

2014 – Air, Climate, and Energy Centers. These centers are investigating regional differences in air pollution and the effects of global climate change, technology, and societal choices on local air quality and health.

BOX 4-2 Children's Environmental Health and Disease Prevention Research Centers

- The Children's Centers were established in response to Federal Executive Order 13045, "Protection of Children from Environmental Health Risks and Safety Risks", which mandated Federal agencies to place a high priority on identifying and assessing risks affecting children (62 Fed. Reg. 1988 [1997]).
- 1998-2014 EPA and NIEHS have jointly released a series of 8 RFAs, which have supported 23 centers. The RFAs have focused on understanding environmental threats to children's health and well-being. The goals of this research are to understand how environmental factors affect children's health, and promote the translation of basic research findings into intervention and prevention methods to prevent adverse health outcomes associated with environmental stressors (NIEHS/EPA 2013).
- The Children's Centers have led to an improved understanding of the environmental impacts on child health and development. Some major findings include:
  - Health implications to children from exposure to emissions from diesel trucks (Gauderman et al. 2002)
  - Children from stressful households have an increased risk of developing asthma when exposed to traffic related air pollution (Shankardass et al. 2009)
  - Evidence of traffic as a major risk factor for the development of obesity in children (Jerrett et al., 2010).
  - Exposure to polycyclic aromatic hydrocarbons in air has negative impacts on neurophysiology (Perera et al. 2012).
  - Obesity increases susceptibility to indoor air pollutants (Lu et al. 2013)
  - Declining NO_2 and $PM_{2.5}$ are associated with improved lung function (Gauderman et al. 2015).

In addition to these large sustained efforts, STAR has been used by EPA to fill many other scientific knowledge gaps. An example occurred in 2006 when the Clean Air Scientific Advisory Committee (CASAC) recommended changing the indicator in the National Ambient Air Quality Standard (NAAQS) from PM_{10} (PM <10 μm) to $PM_{10\text{-}2.5}$ (PM 10μm-2.5 μm) (CASAC 2006). However, significant uncertainties were identified in understanding the links between $PM_{10\text{-}2.5}$ exposure and adverse health effects. As a result, EPA released a STAR RFA on the Source, Composition, and Health Effects of Coarse Particulate Matter in 2006, which awarded five grants which compared the heterogeneity, composition, sources and toxicity of $PM_{10\text{-}2.5}$.

STAR research helped address scientific issues identified in an international public health effort in 2012. In 2010, the United Nation's Alliance, with backing from the U.S. government, launched the Global Alliance for Clean Cookstoves, which aimed to foster the adaptation of clean cookstoves and fuels in 100 million households by 2020 (Martin et al. 2011). However, as more investment was being made in cookstove interventions, there were significant uncertainties about the feasibility of decreasing overall emissions and the real-world benefits of interventions for health and climate (Hanna et al. 2012). STAR responded to these questions with the 2012 RFA, Measurements and Modeling for Quantifying Air Quality and Climatic Impacts of Residential Biomass or Coal Combustion for Cooking, Heating, and Lighting. As a result of the RFA, STAR is currently funding 6 research teams led by U.S. institutions working with a variety of academic, community, and government organizations in Alaska, China, India, Nepal, Mongolia, Ghana, Uganda, and Honduras. This research aims to generate technologies that will inform global efforts to decrease the impacts of household air pollution on health and the role of climate on as a modifying factor. Moreover, understanding cookstoves and residential energy demands may help answer questions about broader issues of sustainable energy development and consumption in the United States and in the developing world (EPA 2015a).

STAR has also addressed how new and emerging technologies may impact human health and the environment. For example, in the early 2000s, as the use of engineered nanoparticles became more prevalent, STAR, in collaboration with other federal research programs, released several RFAs aimed at understanding the potential health effects of the new materials. From 2003 to 2015, STAR released 9 RFAs on this topic which supported 78 grants. The research funded by these grants has evaluated the impacts of engineered nanoparticles very broadly in different environments, such as soil, water (aquifers), the food chain, and wastewater, and how alterations in the chemistry of engineered nanoparticles influence the potential for adverse human health and ecosystem impacts (NRC 2013b, EPA 2017).

STAR also has addressed new technologies through the evaluation of air sensors for citizen science. Recently, low-cost, portable sensors to measure air pollutants have allowed individuals and community groups to measure concentrations of various air pollutants. While these sensors can potentially provide helpful information, the accuracy and durability of these sensors have not been widely tested in a community framework (Vallano et al. 2012). In response to this, EPA issued an RFA in 2014 titled Air Pollution Monitoring for Communities and awarded six grants which funded research teams to work with community groups to understand how low-cost, portable air sensors perform in real-world conditions.

The STAR program has addressed knowledge gaps that are identified on the basis of environmental emergencies. For example, after the Deep Water Horizon oil spill in 2010, STAR released an RFA in 2011 on the environmental effects and mitigation of oil spills. EPA has awarded STAR research grants to strengthen public health and ecosystem protection from oil spill contaminants in the Gulf of Mexico. From this RFA, STAR funded four grants, all of which partnered with Gulf state universities. The research teams collaborated with affected communities who helped identify risks posed by oil spills and obtained their input in the design of their research strategy. The goal of this effort was to minimize the risk of delays in treating oil spills and empower Gulf communities to participate in the decision-making process related to mitigation of environmental impacts.

The STAR program has also been used to address exposure science research needs and collaboration among agencies identified in the National Academies Exposure Science in the 21st Century report (NRC 2012b). The STAR program released an RFA that resulted in five grants related to New Methods in 21st Century Exposure Science in 2015. The research supported by these grants is focused on developing new methods to characterize exposure to chemicals associated with consumer products in indoor environments (EPA 2015b). This program is complementary to the much larger Exposure Biology and the Exposome program at NIEHS, which has generally focused on creating tools and research capacity for detection of biomarkers and wearable sensor technology (NIEHS 2016).

STAR announced an RFA on Indoor Air and Climate Change RFA announced in 2012 in response to the growing awareness that climate change may both introduce and worsen indoor environmental problems, and that there was a significant gap in knowledge between the intersection of indoor air quality, climate change, and health (IOM 2011). The research supported by the grants awarded under this RFA aims to develop more energy efficient designs and ways to adapt buildings to climatic changes.

To encourage small water systems (systems that serve 10,000 or fewer people) to try novel approaches to addressing drinking water challenges, STAR has released two RFAs focused on innovation in small drinking water systems, Research and Demonstration of Innovative Drinking Water Treatment Technologies in Small Systems (2011) and National Centers for Innovation in Small Drinking Water Systems (2013). Research and Demonstration of Innovative Drinking Water Treatment Technologies in Small Systems led to 11 different grants which aimed to develop technologies that are sustainable and able to treat or mitigate groups of contaminants or contaminant precursors in drinking water sources and systems. The RFA National Centers for Innovation in Small Drinking Water Systems led to the creation of two National Research Centers which aim to develop and demonstrate innovative technologies to better reduce, control, and eliminate chemical or microbial contaminants in small water systems (EPA 2016).

STAR research can also evaluate the possible adverse consequences of resource conservation practices aimed at environmental protection; in 2014, STAR released an RFA on human and ecologic health effects associated with water reuse and conservation practices. From this RFA, STAR awarded five grants; the goals of the grants are to measure health and ecological impacts of water conservation practices such as potable reuse and agricultural water reuse (EPA 2014).

The examples show how EPA uses the STAR program to address important environmental challenges facing the nation. While other federal agencies can and have supported research in disciplines and topic areas that are somewhat similar to STAR, that research is often not directed toward addressing scientific questions related to clean air and drinking water, toxic substances, and ecosystem health. The ability of EPA to use STAR to address a variety of important research questions has decreased in recent years because STAR has not had the ability to release as many RFAs. In 2003, STAR released 12 individual investigator grant RFAs and one center RFA. In 2013 and 2014, STAR released five individual-investigator RFAs and two center RFAs each year. In 2015, it released only one individual-investigator RFA. Additionally, EPA reported instances in recent years where an RFA was developed, but grants were not awarded due to lack of available funds. Examples include an RFA titled "Children's Environmental Health and Disease Prevention Research Centers: understanding environmental factors to improve children's health in child care environments" (RFA developed in 2010 but never released), Developing the Next Generation of Air Quality Measurement Technology (RFA released in 2011, but cancelled during grant award phase), and Air Pollution Meteorology (RFA announced as upcoming on EPA website in 2012, but cancelled before applications were received). This lack of funding clearly limits the number of topics in which the STAR program can invest.

CONCLUSIONS

EPA's mission to protect human health and the environment allows the agency to identify address complex questions about human health and the environment. STAR has been used strategically to support multidisciplinary research which addresses these questions. However, given the declining budget of STAR noted above and in Chapter 1, its ability to support research is being diminished. For example, STAR has released fewer RFAs in recent years and thus not been able to address as many knowledge gaps. The committee is concerned this may impair our nation's ability to tackle important persistent and emerging complex environmental challenges.

REFERENCES

Anton, W.R.Q, G. Deltas, and M. Khanna. 2004. Incentives for environmental self-regulation and implications for environmental performance. J. Environ. Econom. Manage. 48(1):632-654.

Breysse, P.N., R.J. Delfino, F. Dominici, A.C.P. Elder, M.W. Frampton, J.R. Froines, A.S. Geyh, J.J. Godleski, D.R. Gold, P.K. Hopke, P. Koutrakis, N. Li, G. Oberdörster, K.E. Pinkerton, J.M. Samet, M.J. Utell, and A.S. Wexler. 2013. U.S. EPA particulate matter research centers: Summary of research results for 2005-2011. Air Qual. Atmos. Health 6(2):333-355.

Burke, T.A., W.E. Cascio, D.L. Costa, K. Deener, T.D. Fontaine, F.A. Fulk, L.E. Jackson, W.R. Munns, J. Orme-Zavaleta, M.W. Slimak, and VG. Zartarian. 2017. Rethinking environmental protection: Meeting the challenges of a changing world. Environ. Health Perspect. 125(3):A43-A49.

Cao, J., D. Elliott, and W. Zhang. 2005. Perchlorate reduction by nanoscale iron particles. J. Nanopart. Res. 7(4):499-506.

CASAC (Clean Air Scientific Advisory Committee). 2006. Clean Air Scientific Advisory Committee Recommendations Concerning the Final National Ambient Air Quality Standards for Particulate Matter. Memo to Stephen Johnson, Administrator, U.S. Environmental Protection Agency, Washington, DC. EPA-CASAC-LTR-06-003. September 29, 2006 [online]. Available: https://yosemite.epa.gov/sab/sabproduct.nsf/1C69E987731CB775852571FC00499A10/$File/casac-ltr-06-003.pdf [accessed April 27, 2017].

Cason, T.N., and L. Gangadharan. 2004. Auction design for voluntary conservation programs. Am. J. Agricult. Econ. 86 (5):1211-1217.

EPA (U.S. Environmental Protection Agency). 2014. Human and Ecological Health Impacts Associated with Water Reuse and Conservation Practices [online] Available: https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/recipients.display/rfa_id/591 [accessed April 27, 2017].

EPA. 2015a. STAR Measurements and Modeling for Quantifying Air Quality and Climatic Impacts of Residential Biomass or Coal Combustion for Cooking, Heating and Lighting Kick-off Meeting [online] Available: https://www.epa.gov/research-grants/star-measurements-and-modeling-quantifying-air-quality-and-climatic-impacts [accessed April 27, 2017].

EPA. 2015b. STAR New Methods in 21st Century Exposure Science Kick-off Meeting [online] Available: https://www.epa.gov/research-grants/star-new-methods-21st-century-exposure-science-kick-meeting [accessed April 27, 2017].

EPA. 2016. STAR Clean Air Research Centers (CLARCs) Final Progress Review Webinar, June 6, 2016 [online] Available: https://19january2017snapshot.epa.gov/research-grants/star-clean-air-research-centers-clarcs-final-progress-review-webinar_.html [accessed April 27, 2017].

EPA 2017. Increasing Scientific Data on the Fate, Transport and Behavior of Engineered Nanomaterials in Selected Environmental and Biological Matrices. Extramural Research, U.S. Environmental Protection Agency [online]. Available: https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/recipients.display/rfa_id/534 [accessed April 27, 2017].

Fanning, E.W., J.R. Froines, M.J. Utell, M. Lippmann, G. Oberdörster, M. Frampton, J. Godleski, and T.V. Larson. 2009. Particulate matter (PM) research centers (1999-2005) and the role of interdisciplinary center-based research. Environmental Health Perspect. 117(2):167-174.

Gauderman, W.J., G.F. Gilliland, H. Vora, E. Avol, D. Stram, R. McConnell, D. Thomas, F. Lurmann, H.G. Margolis, E.B. Rappaport, K. Berhane, and J.M. Peters. 2002. Association between air pollution and lung function growth in southern California children: Results from a second cohort. Am. J. Respir. Crit. Care Med. 166(1):76-84.

Gauderman, W.J., R. Urman, E. Avol, K. Berhane, R. McConnell, E. Rappaport, R. Chang, F. Lurmann, and F. Gilliland. 2015. Association of improved air quality with lung development in children. N. Engl. J. Med. 372(10): 905-913.

Gunningham, N.A., D. Thornton, and R.A. Kagan. 2005. Motivating management: Corporate compliance in environmental protection. Law Policy 27(2):289-316.

Hanna, R., E. Duflo, and M. Greenstone. 2012. Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves. NBER Working Paper 18033 [online]. Available: http://www.nber.org/papers/w18033.pdf [accessed May 23, 2017].

IOM (Institute of Medicine). 2011. Climate Change, the Indoor Environment, and Health. Washington, DC: The National Academies Press. Jerrett, M., R. McConnell, R. Chang, J. Wolch, K. Reynolds, F. Lurmann, F. Gilliland, and K. Berhane. 2010. Automobile traffic around the home and attained body mass index: A longitudinal cohort study of children aged 10-18 years. Prev. Med. 50(S1):S50-S58.

Karnik, B.S., S.H.R. Davies, K.C. Chen, D.R. Jaglowski, M.J. Baumann, and S.J. Masten. 2005. Effects of ozonation on the permeate flux of nanocrystalline ceramic membranes. Water Res. 39(4):728-734.

Lee, S., and W.M. Sigmund. 2003. Formation of anatase TiO 2 nanoparticles on carbon nanotubes. Chem. Commun. 6:780-781.

Lu, K.D., P.N. Breysse, G.B. Diette, J. Curtin-Brosnan, C. Aloe, D.L.Williams, R.D. Peng, M.C. McCormack, and E.C. Matsui. 2013. Being overweight increases susceptibility to indoor pollutants among urban children with asthma. J. Allergy Clin. Immunol. 131(4):1017-1023.

Martin, W.J., R.I. Glass, J.M. Balbus, and F.S. Collins. 2011. A major environmental cause of death. Science 334(6053):180-181.

McDaniels, T.L., and M.J. Small. 2004. Risk Analysis and Society: An Interdisciplinary Characterization of the Field. Cambridge, UK: Cambridge University Press.

NIEHS (National Institute of Environmental Health Sciences). 2016. Exposure Biology and the Exposome [online] Available: https://www.niehs.nih.gov/research/supported/exposure/bio/ [accessed April 27, 2017].

NIEHS/EPA. 2013. NIEHS/EPA Children's Environmental Health and Disease Prevention Research Centers: Protecting Children's Health for a Lifetime [online]. Available: https://www.niehs.nih.gov/research/supported/assets/docs/a_c/fact_sheet_niehsepa_centers_for_childrens_environmental_health_and_disease_prevention_research_protecting_childrens_health_for_a_lifetime_508.pdf [accessed April 27, 2017].

NRC (National Research Council). 1998. Research Priorities for Airborne Particulate Matter: I. Immediate Priorities and Long-Range Research Portfolio. Washington, DC: National Academy Press.

NRC. 2012a. Science for Environmental Protection: The Road Ahead. Washington, DC: The National Academies Press.

NRC. 2012b. Exposure Science in the 21st Century: A Vision and a Strategy. Washington, DC: The National Academies Press.

NRC. 2013. Research Progress on Environmental, Health, and Safety Aspects of Engineered Nanomaterials. Washington, DC: The National Academies Press.

Perera, F.P., D. Tang, S. Wang, J. Vishnevetsky, B. Zhang, D. Diaz, D. Camann, and V. Rauh. 2012. Prenatal polycyclic aromatic hydrocarbon (PAH) exposure and child behavior at age 6-7 years. Environ. Health Perspect. 120(6):921-926.

Plevin, R.J., A.D. Jones, M.S. Torn, and H.K. Gibbs. 2010. Greenhouse gas emissions from biofuels' indirect land use change are uncertain but may be much greater than previously estimated. Environ. Sci. Technol. 44(21):8015-8021.

Salzman, J., B.H. Thompson, Jr., and G.C. Daily. 2001. Protecting ecosystem services: Science, economics, and law. Stanford Environ. Law J. 20:309-332.

Shankardass, K, R. McConnell, M. Jerrett, J. Milam, J. Richardson, and K. Berhane. 2009. Parental stress increases the effect of traffic-related air pollution on childhood asthma incidence. Proc. Natl. Acad. Sci. U.S.A. 106(30):12406-12411.

Teisl, M.F., J. Rubin, and C.L. Noblet. 2008. Non-dirty dancing? Interactions between eco-labels and consumers. J. Econ. Psychol. 29(2):140-159.

Vallano, D., E. Snyder, V. Kilaru, E. Thoma, R. Williams, G. Hagler, and T. Watkins. 2012. Air pollution sensors: Highlights from an EPA workshop on the evolution and revolution in low cost participatory air monitoring. EM (December):28-33.

Weber, C.L., and H.S. Matthews. 2008. Food-miles and the relative climate impacts of food choices in the United States. Environ. Sci. Technol. 42(10):3508-3513.

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Findings and Recommendations

Our nation is confronted with old and new environmental challenges that require strategic investigation and better integration between the health, ecologic, economic, and social sciences (Samet et al. 2017). The present report has shown that through the Science to Achieve Results (STAR) program the Environmental Protection Agency (EPA) has created a vehicle that fosters collaboration and knowledge-sharing, which have produced research that has supported interventions that protect public health. STAR allows academic and nonprofit institutions to use new ideas and methods to solve environmental problems; it stimulates a flow of new people into environmental-research careers, and it supports the continued robustness of environmental research (NRC 2012). The importance of research findings from STAR grants are expected to grow as the interdisciplinary nature of environmental problems gains wider recognition. EPA is not the only organization that reaps STAR's benefits. Many other institutions that work directly or indirectly to protect human health and the environment also benefit. Two examples of other entities that STAR grants benefit are regulated industries that can use new technologies to more effectively reduce pollution at lower costs and state governments that can use improved environmental monitoring and modeling methods to meet Clean Air Act mandates.

The key findings and recommendations that the committee thinks will help STAR to remain an important research program are summarized below. They are organized by scientific merit, public benefits, and research priorities.

SCIENTIFIC MERIT

The committee found that the STAR program used procedures, for priority setting, soliciting, awarding, and administering grants support research of high scientific merit. Having compared STAR's procedures with those of other research programs, the committee found no major deficiencies in the STAR's procedures for priority-setting, development of requests for applications (RFAs), awarding of grants, or management of grant performance (Chapter 2). The priority-setting procedures for STAR are integrated within four of the EPA Office of Research and Development national programs; this allows STAR to be flexible in light of the nation's changing research priorities and avoids duplication of EPA's internal research. STAR was the only research program included in the comparison that allowed neither submission of research topics by the general public nor submission of unsolicited proposals; this may limit the creativity of the program.

The committee's review of the RFAs led it to note that the STAR program's RFAs are generally of good quality and address a wide variety of topics. STAR has strong peer-review procedures, and it is a highly competitive program, with a median grant application award rate of 16% from 2003-2014 (Chapter 2). After peer review, EPA staff review grant applications for relevance to the intent of the RFA, but it is unclear whether applicants receive feedback on their applications' relevance review.

- **Finding 1. EPA has high-quality procedures for priority-setting that allow STAR to be integrated within EPA's research program.**
  - ➢ **Recommendation 1. EPA should continue to use its procedures strategic planning and for setting priorities for STAR research. However, EPA should consider developing a**

mechanism to allow for public input to the STAR research agenda or the submission of unsolicited proposals.

- **Finding 2: STAR's procedures to develop funding announcements and award grants ensure that the program sponsors research of high scientific merit.**
  - ➢ **Recommendation 2. The STAR program should maintain the procedures that it has in place. However, it should provide comments to applicants whose applications were not awarded because of lack of relevance so that they can improve their ability to prepare future grant proposals.**

PUBLIC BENEFITS

The STAR program is productive. In 2003-2015, STAR awarded 541 individual-investigator grants, 53 center grants, and 800 fellowships (Chapter 1). From October 2002-April 2017, EPA reported there were 5,760 STAR journal publications that acknowledged STAR funding (Chapter 3). The committee found that STAR research is used by many organizations in developing decision documents, such as federal, state or local government documents, international guidelines, and documents of academic or non-profit organizations, such as National Research Council reports and American Public Health Association guidelines. In 2012, at least 105 STAR-funded papers were cited in those documents. The committee found that STAR outputs and outcomes have led to numerous public benefits (Chapter 3). Some examples are the development of an environmental-science workforce, the development of human-resources and research infrastructure around the country nation, reduction in the costs of compliance with environmental regulation, provision of a scientific basis for decisions required to protect public health and the environment, and study of new methods to improve environmental management.

Support of Public-Health Decisions

STAR research results have supported numerous public-health decisions (Chapter 3). The STAR program supported several large initiatives focused on the human-health effects of air pollution, such as the Particulate Matter Centers, the Clean Air Research Centers, and now the Air, Climate, and Energy Centers. Studies supported by the centers have shown that increased exposure to air pollution leads to a decrease in life expectancy; examples include a followup of the Harvard Six Cities Study (Laden et al. 2006) and a large ecologic study of $PM_{2.5}$ exposure and mortality in 51 US cities (Pope et al. 2009). The findings supported those of earlier research and led to the development of a more scientifically justified $PM_{2.5}$ national ambient air quality standard (NAAQS) (EPA 2012).

Another initiative that has had a major public-health impact is the Children's Environmental Health and Disease Prevention Research Centers. These STAR center grants are funded in partnership with the National Institute of Environmental Health Sciences and aim to evaluate the impacts of environmental exposures on child health and development. In 2016, a research project partially supported by a STAR grant recognized that infants could be exposed to arsenic through rice cereal (Karagas et al. 2016), and this recognition led the Food and Drug Administration to propose regulations to protect infant health (FDA 2016). Another example is the discovery by the University of Washington Children's Center that farmworker children had increased exposure to the pesticide ingredient azinphos-methyl which is a neurotoxicant (Curl et al. 2002), which informed EPA's decision to phase out the use of azinphos-methyl (EPA 2006).

Examples of STAR research to improve environmental management include experiments in market-based incentives to lower emissions, studies that evaluate the potential reduction in costs of pollution abatement (Anton et al. 2004), and auctions in which landowners and land sellers compete to obtain part of a fixed budget allocated by the regulator to subsidize pollution abatement (Cason and Gangadharan 2004).

Reducing the Cost of Compliance with Regulation

Some STAR research grants have led to reductions in the cost of complying with environmental regulations (Chapter 3). The cost reductions benefit regulated industries and states and localities that need to comply with environmental regulations. An example of STAR research that may benefit industry is the development of a tissue-based method for evaluating the thyroid effects of chemical exposures (Hutson et al. 2016); this may reduce the cost of chemical testing compared with animal-based approaches. STAR research has expanded the capability of air-pollution models by identifying key chemical species and reactions that occur in cloud droplets that lead to PM formation; the improved models reduce the costs of compliance with $PM_{2.5}$ NAAQSs (Carlton et al. 2008). Another research project supported by STAR discovered a potentially cost-effective method for removing nitrate from drinking water (Berquist et al. 2016).

Workforce Development

In 2003-2015, STAR awarded 800 graduate fellowships. Many former STAR fellows continued in environmental and environmental-health sciences careers. Of former STAR fellows who reported to EPA on their career trajectories, 34% in postdoctoral positions, 21% in teaching positions, 16% in research positions, 12% in the federal government, 5% in consulting firms, 4% in state, local, or tribal governments, 4% in private industry, and 3% in nonprofits. The committee found evidence that STAR fellows had produced high-quality science: it found in a Google Scholar search for STAR publications with more than 100 citations, that about one-fourth were at least partially supported by STAR fellowships (Chapter 3).

Infrastructure Development

In FY 2014, the STAR program had grantees or fellows in all but two states (Vermont and South Dakota) (Chapter 3). Engagement with EPA in institutions throughout the United States has created communities of scientists and engineers working in the human health and environmental sciences that might not have existed without support from STAR grants. Research grants also help to improve facilities for data collection and analysis in the supported grantees' institutions.

Tracking of Public Benefits of Research Supported by the Science to Achieve Results Program

Tracking of the public benefits of research is difficult; all research programs struggle with tracking and then attributing public benefits to specific research projects. One issue that made it difficult for the committee's evaluation of STAR is that the EPA grantee project results Web site was not up to date. In many cases, annual or final reports for grants that had long been completed or were in operation for a number of years were unavailable (see Chapter 2). That may seem like a minor criticism, but the grantee project results site is used as a resource by academic researchers who are conducting literature reviews and to the public to understand the benefits of the STAR program's research (Yuen et al. 2015).

STAR has made efforts to translate research results for a broader audience and to synthesize information on a given RFA topic by having investigators on different grants collaborate to create summary reports, but the efforts have been somewhat inconsistent (see Chapter 3). Relaying the overall benefits of the research could be strengthened if center grantees consistently created synthesis reports and held more public webinars to discuss their research results.

The committee acknowledges that many other research programs struggle with such challenges (see Chapter 3). Evaluations like the present one would be improved if there were more robust electronic databases that could be easily searched to detect linkages between grants, fellowships, and public benefits. There have been advances throughout the federal government to mine existing data in reports, literature, administrative records, and so forth, to identify intermediate outcomes more effectively, to link federally funded projects to long-term effects, and to track career outcomes of graduate students supported by fellowships or graduate research assistantships. The National Institutes of Health (NIH), for example, has created the High Impacts Tracking System. The system loads progress reports and program officers' notes about grants into a searchable system and allows structured tagging of outputs and effects. Another NIH example is RePARS, which permits automatic retrieval of sources of NIH funding of publications in any list, such as the bibliography of a National Academies report (Drew et al. 2016). Those efforts have recently been used to show the effects of the National Toxicology Program, for example, to evaluate the program's impacts on a water-quality standard for hexavalent chromium in California (Xie et al. 2017). EPA could make strides in this regard by collaborating with other organizations.

EPA would benefit from working with other federal agencies that are advancing ways in which the value of research is communicated to the public. NIH has found that the links between research studies and benefits to human health are described best in stories or case studies that resonate with those outside the research community. EPA should consider reporting stories more prominently on its Web site and blogs. STAR should also consider requiring grantees to report the potential influence and public benefits of their awards as part of their final reports and even 5-10 years after their research has been completed.

The Fellowship Program

As discussed previously, the STAR fellowship program supported students who continued careers in environmental and environmental- health sciences. The STAR fellowship program was distinctive in that it covered both environmental and environmental-health research. The two other agencies that support predoctoral fellows will not fill the gap left by the discontinuation of the STAR program: National Science Foundation (NSF) training programs do not cover environmental health effects and are focused on basic science projects while NIH training programs are geared toward overall health sciences, not specifically the environment on human health. In addition, it appears that the move to centralize graduate fellowships in NSF has led to a large reduction in the support of students interested in environmental research. In 2017, after the STAR fellowship program was cancelled, the number of NSF fellows in environmental science and ecologic research were essentially unchanged at 176, thus cancelling the STAR fellowship program resulted in many fewer fellowships in environmental and environmental health sciences (Chapter 1). The need for federally supported fellowship programs in the environmental arena is important as the United States is projected to have considerable human-resources needs in the science, engineering, and policy fields (NAS/NAE/IOM 2007).

- **Finding 3. The STAR program has generated research that has many public benefits. However, these public benefits are not consistently tracked and synthesized.**
    - ➢ **Recommendation 3. The STAR program should partner with other federal agency efforts to improve communication of the benefits of its research to the public. In addition, EPA should update the grantee project results Web site.**
- **Finding 4. The STAR fellowship program was critical for training future generations of scientists who pursue environmental careers.**
    - ➢ **Recommendation 4. The STAR fellowship program should be restored to EPA given the continued and growing need for scientists in environmental research and management.**

RESEARCH PRIORITIES

The committee found that STAR supports work in almost every field identified that contributes to environmental knowledge and capacity. The most common fields identified were the atmospheric sciences, climate sciences, ecology, environmental economics, environmental engineering, human exposure and health effects, risk analysis, systems modeling and decision support, and innovative risk management (Chapter 4). Many other federal research programs support scientific study in those fields. What distinguishes STAR from the other programs? The committee found that STAR's distinguishing characteristics lie not in the research topics that it supports but in the fact that it is used strategically by EPA to address critical knowledge gaps that need to be filled to protect human and ecosystem health.

Examples of how EPA has used STAR to address knowledge gaps strategically or to respond to emerging challenges are numerous (Chapter 4). STAR has been called on to address human health and environmental concerns related to new technology, to address problems identified in the event of environmental disasters, and to evaluate potential consequences of resource-conservation technologies. Some recent examples are the release of RFAs that cover health effects of engineered nanoparticles, environmental effects and mitigation of oil spills after the Deepwater Horizon spill, and human and ecologic effects associated with water reuse and conservation practice (Chapter 4, Appendix C).

The ability of EPA to use STAR in those ways has declined in recent years; EPA has not had the ability to release as many STAR RFAs. In 2003, there were 12 STAR individual-investigator grant RFAs and one center RFA. In each of 2013 and 2014, there were five individual-investigator STAR RFAs and two center STAR RFAs. In 2015, EPA released only one individual-investigator STAR RFA. The reduction in RFAs limits the number of topics in which the EPA is investing in through the STAR program.

- **Finding 5. STAR plays a distinctive role in the nation's overall environmental-research portfolio.**
  - ➢ **Recommendation 5. The committee recommends that EPA continue to use STAR to respond to the nation's emerging environmental challenges.**

CONCLUSIONS

The STAR program was born out of the need for EPA to have access to environmental researchers in academic and nonprofit organizations through extramurally funded projects, centers, and fellowships. STAR has had numerous successes, such as in research on human health implications of air pollution, on environmental effects on children's health and well-being, on interactions between climate change and air quality, and on the human health implications of nanoparticles. Those are just a few examples; many more could be cited. As the committee looks to the future, it sees a pressing need for environmental research to address complex emerging and persistent environmental challenges. The STAR program supports research that is aimed at improving decision-making, problem detection, and problem-solving; it is an important mechanism through which the nation can gain the knowledge needed to respond to these challenges.

REFERENCES

Anton, W.R.Q, G. Deltas, and M. Khanna. 2004. Incentives for environmental self-regulation and implications for environmental performance. J. Environ. Econ. Manage. 48(1):632-654.

Bergquist, A.M., J.K. Choe, T.J. Strathmann, and C.J Werth. 2016. Evaluation of a hybrid ion exchange-catalyst treatment technology for nitrate removal from drinking water. Water Res. 96(1):177-187.

Carlton, A.G., B.J. Turpin, K.E. Altieri, S.P. Seitzinger, R. Mathur, S.J. Roselle, and R.J. Weber. 2008. CMAQ model performance enhanced when in-cloud secondary organic aerosol is included: Comparisons of organic carbon predictions with measurements. Environ. Sci. Technol. 42 (23):8798-8802.

Cason, T.N, and L. Gangadharan. 2004. Auction design for voluntary conservation programs. Am. J. Agr. Econ. 86(5):1211-1217.

Curl, C.L., R.A. Fenske, J.C. Kissel, J.H. Shirai, T.F. Moate, W. Griffith, G. Coronado, and B. Thompson. 2002. Evaluation of take-home organophosphorus pesticide exposure among agricultural workers and their children. Environ. Health Perspect. 110(12):A787-A792.

Drew, C.H., K.G. Pettibone, F.O. Finch III, D. Giles, and P. Jordan. 2016. Automated research impact assessment: A new bibliometrics approach. Scientometrics 106(3):987-1005.

EPA (U.S. Environmental Protection Agency). 2006. Interim Reregistration Eligibility Decision for Azinphos-Methyl Case No. 0235. Office of Pesticide Protection, Washington, DC [online]. Available: https://archive.epa.gov/pesticides/reregistration/web/pdf/azinphosmethyl_ired.pdf [accessed April 27, 2017].

EPA. 2009. Integrated Science Assessment for Particulate Matter. EPA/600/R-08/139F. National Center of Environmental Assessment RTP Division, Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC [online]. Available: https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=216546 [accessed May 24, 2017].

EPA. 2012. Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. EPA/600/R-12/056F. National Center of Environmental Assessment RTP Division, Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC [online]. Available: https://www3.epa.gov/ttn/naaqs/standards/pm/data/20121213psa.pdf [accessed April 27, 2017].

FDA (U.S. Drug and Food Registration). 2016. FDA proposes limit for inorganic arsenic in infant rice cereal. FDA News Release: April 1, 2016 [online]. Available: https://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm493740.htm [accessed May 24, 2017].

Hutson, M.S., P.G. Alexander, V. Allwardt, D.M Aronoff, K.L. Bruner-Tran, D.E. Cliffel, J.M. Davidson, A. Gough, D.A. Markov, L.J. McCawley, J.R. McKenzie, J.A. McLean, K.G. Osteen, V. Pensabene, P.C. Samson, N.K. Senutovitch, S.D. Sherrod, M.S. Shotwell, D.L. Taylor, L.M. Tetz, R.S. Tuan, L.A. Vernetti, and J.P. Wikswo. 2016. Organs-on-chips as bridges for predictive yoxicology. Appl. In Vitro Toxicol. 2(2):97-102.

Karagas, M.R., T. Punshon, V. Sayarath, B.P. Jackson, C.L. Folt, and K.L. Cottingham. 2016. Association of rice and rice-product consumption with arsenic exposure early in life. JAMA Pediatr. 170(6):609-616.

Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. Reduction in fine particulate air pollution and mortality: Extended follow-up of the Harvard Six Cities study. Am. J. Respir. Crit. Care Med. 173(6):667-672.

NAS/NAE/IOM (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine). 2007. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, DC: The National Academies Press.

NRC (National Research Council). 2012. Science for Environmental Protection: The Road Ahead. Washington, DC: The National Academies Press.

Pope, C.A., M. Ezzati, and D.W. Dockery. 2009. Fine-particulate air pollution and life expectancy in the United States. N. Engl. J. Med. 360(4):376-386.

Samet, J.M., T.A. Burke, and B.D. Goldstein. 2017. The Trump Administration and the environment—heed the science. N. Engl. J. Med. 376(12):1182-1188.

Xie, Y., S. Holmgren, D.M.K. Andrews, and M.S. Wolfe. 2017. Evaluating the impact of the US National Toxicology Program: A case study on hexavalent chromium. Environ. Health Perspect. 125(2):181-188.

Yuen, T., A.N. Park, S.D. Seifer, and D. Payne-Sturges. 2015. A systematic review of community engagement in the U.S. Environmental Protection Agency's extramural research solicitations: Implications for research funders. Am. J. Public Health 105(12): e44-e52.

Appendix A

Biographical Information of the Committee on the Review of EPA's Science to Achieve Results Research Grants Program

Mark J. Utell (*Chair*) is a professor of medicine and environmental medicine, the director of occupational and environmental medicine, and the former director of pulmonary and critical care medicine at the University of Rochester Medical Center. His research interests have centered on the effects of environmental toxicants on the human respiratory tract. Dr. Utell has published extensively on the health effects of inhaled gases, particles, and fibers in the workplace and other indoor and outdoor environments. He was the co-principal investigator of a U.S. Environmental Protection Agency (EPA) funded particulate matter research center and is a former chair of the Health Effects Institute's research committee. He has served as chair of EPA's Environmental Health Committee and on the executive committee of the EPA Science Advisory Board. He is a former recipient of the National Institute of Environmental Health Sciences Academic Award in Environmental and Occupational Medicine and the Mercer Award from the International Society for Aerosols in Medicine. Dr. Utell has served on several National Academies committees, including the Committee to Review the NIOSH Respiratory Disease Research Program; Committee to Review the Department of Defense Enhanced Particulate Matter Surveillance Program Report; Committee on Research Priorities for Airborne Particulate Matter; Committee on Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials; Committee to Review the Department of Labor's Site Exposure Matrix; and Committee on Gulf War and Health: Literature Review of Selected Environmental Agents, Pollutants, and Synthetic Chemical Compounds. He also served on the Board on Environmental Studies and Toxicology. He received his M.D. from Tufts University School of Medicine.

Praveen K. Amar is an independent consultant in the areas of air environment, energy, and climate change strategies. He is currently working as a member of the Technical Experts Group for the United Nations Environment Program (UNEP) in implementing the global treaty on reducing emissions of mercury under the Minamata Convention. From May 2011 to May 2013, he was the Senior Policy Advisor of Technology and Climate Policy at the Clean Air Task Force (CATF), an environmental organization with a focus on protecting the environment through research, advocacy, collaboration, and innovation. Before joining CATF, Dr. Amar worked with NESCAUM, a nonprofit association of air quality agencies in the Northeast for 19 years, including 16 years as its Director of Science and Policy, where his key role was to translate the implications of findings of science and developments in technology into workable and cost-effective policy options for the Northeast states. While at NESCAUM, his research projects focused on monetizing the public health benefits of controlling mercury emissions from coal-fired power plants in the U.S. and evaluating future impacts of global climate change on regional ground-level air quality in the U.S. (ozone and fine particles). Before NESCAUM, Dr. Amar was affiliated with the California Air Resources Board (1977-1992), where he managed programs on air pollution research (including research on acid deposition, atmospheric processes, and ecological effects), strategic planning, and industrial source pollution control. He was a member of the U.S. EPA's Advisory Council on Clean Air Compliance Analysis. From 2007-2011, he served as a member of EPA's Clean Air Scientific Advisory Committee (CASAC) panel on review of Secondary National Ambient Air Quality Standards (NAAQS) for SO_2 and

NOx. Since 2015, he has been serving on the reconstituted CASAC review panel on review of the secondary NAAQS for SO_2 and NOx. He recently completed his service on EPA's Clean Air Act Advisory Committee (CAAAC) Climate Change Work Group that addressed approaches EPA may take to control greenhouse gas emissions from large industrial sources. He is a member of the National Academies Board on Environmental Studies and Toxicology. Dr. Amar also serves on the Science Advisory Committee for the New York State Energy Research and Development Authority (NYSERDA) environmental research program. He has taught graduate courses in atmospheric processes and air pollution policy at the University of California at Davis, California State University at Sacramento, and Tufts University in Boston. Dr. Amar is a registered professional engineer in the State of California. He received his Ph.D. in engineering from the University of California at Los Angeles.

Marian R. Chertow is Associate Professor of Industrial Environmental Management at the Yale School of Forestry and Environmental Studies. Her research and teaching focus on industrial ecology, business/environment issues, waste management, urban-industrial issues, and environmental technology innovation. Current research interests are: (1) industrial symbiosis involving geographically based exchanges of materials, energy, water and wastes within networks of businesses; (2) industrial ecology and circular economy in resource-poor, emerging economies; (3) material and energy studies to quantify and compare physical flows through urban areas especially in India and China. Prior to Yale, Professor Chertow spent ten years in environmental business and state and local government, including service as president of a large state bonding authority charged with developing a waste infrastructure system. She is a frequent international lecturer and has testified on waste, recycling and other environmental issues before committees of the U.S. Senate and House of Representatives. She is a frequent international lecturer, serves on the Board of Directors of the Alliance for Research in Corporate Sustainability (ARCS), the External Advisory Board of the Center for Energy Efficiency and Sustainability at Ingersoll Rand, and served as the elected President of the International Society of Industrial Ecology, her scholarly society, until 2015. She is also appointed at the Yale School of Management and serves on the founding faculty of the Masters of Science in Environmental Management Program at the National University of Singapore where she teaches "Business and Environment." She received her Ph.D. in environmental studies from Yale University.

Susan E. Cozzens is Vice Provost for Graduate Education and Faculty Development at the Georgia Institute of Technology, where she is also professor of public policy and director of the Technology Policy and Assessment Center. Dr. Cozzens's research interests are in science, technology, and innovation policies in developing countries, including issues of equity, equality, and development. She is active internationally in developing methods for research assessment and science and technology indicators. From 1995 through 1997, Dr. Cozzens was director of the Office of Policy Support at the National Science Foundation (NSF). The Office of Policy Support coordinated policy and management initiatives for the NSF director, primarily in peer review, strategic planning, and assessment. Her prior service on committees of the National Academies includes the Committee on the Review of NIOSH Research Programs and the Committee on Evaluating the Efficiency of Research and Development Programs at the Environmental Protection Agency. Dr. Cozzens holds a Ph.D. in sociology from Columbia University.

Bart E. Croes is the Chief of the Research Division for the California Air Resources Board, with responsibilities for California's ambient air quality standards; climate change science and mitigation of high global warming potential gases; health, exposure, atmospheric processes, and emissions control research; and indoor air quality. He was the Public Sector Co-Chair for the NARSTO Executive Assembly, a former member of the National Research Council Committee on Research Priorities for Airborne Particulate Matter, and the Committee on Energy Futures and Air Pollution in Urban China and the United States, a joint collaboration between the National Academy of Engineering, National Research Council, Chinese Academy of Engineering, and Chinese Academy of Sciences. He has been a peer reviewer for the National Research Council, the U.S. Environmental Protection Agency, and numerous journals, and received the

Editors' Citation for Excellence in Refereeing from the Journal of Geophysical Research. Mr. Croes has published peer-reviewed articles on air quality simulation modeling, emission inventory evaluation, reactivity-based VOC controls, toxic air contaminants, acid deposition, the weekend effect for ozone and PM, PM data analysis and trends, diesel particle traps, and climate change impacts on California. He received an M.S. degree in chemical engineering from the University of California at Santa Barbara.

Ana V. Diez Roux (NAM) is a Distinguished University Professor of Epidemiology and dean of the Dornsife School of Public Health at Drexel University. Originally trained as a pediatrician in her native Buenos Aires, she completed public health training at the Johns Hopkins University School of Hygiene and Public Health. Before joining Drexel University, she served on the faculties of Columbia University and the University of Michigan, where she was chair of the Department of Epidemiology and director of the Center for Social Epidemiology and Population Health at the University of Michigan School of Public Health. Dr. Diez Roux is internationally known for her research on the social determinants of population health and the study of how neighborhoods affect health. Dr. Diez Roux has served on numerous editorial boards, review panels and advisory committees including the Board of Scientific Counselors (BSC) of the National Center for Health Statistics, the Committee on Health and Wellbeing in the Changing Urban Environment of the International Council for Science (ISCUS), and the Editorial Board of the Annual Review of Public Health. She currently serves as chair of the U.S. Environmental Protection Agency's Clean Air Scientific Advisory Committee and a member of the agency's Science Advisory Board. She was awarded the Wade Hampton Frost Award for her contributions to public health by the American Public Health Association. She is an elected member of the American Epidemiological Society and the Academy of Behavioral Medicine Research. She was elected to the National Academy of Medicine in 2009. Dr. Diez Roux received an M.D. from the University of Buenos Aires.

Kimberly A. Gray is the chair of the Civil and Environmental Engineering Department and Professor of Civil and Environmental Engineering and Chemical and Biological Engineering at Northwestern University. Dr. Gray's areas of expertise are environmental catalysis and physicochemical processes in natural and engineered environmental systems with particular focus on energy and urban sustainability applications. She studies the synthesis, characterization and performance of photo-active materials, principally TiO2-based nanocomposites for solar fuel production and water/air treatment. Work in her group also involves the investigation of chemical fate in natural systems. She probes the role of periphyton (algal biofilms) in contaminant accumulation in stream sediments and in denitrification in wetlands. She studies the ways in which detailed understanding of ecological relationships (periphyton structure and dynamic food web descriptions) improves our ability to predict chemical transfer (bioaccumulation) in aquatic systems and ultimately human health risks. Application of this research is important in efforts to restore critical ecosystems (Great Lakes), to make ecological forecasts in the face of climate change and to employ ecosystem function for environmental protection (treatment wetlands). She is also studying the unintended ecotoxicological impacts of nanomaterials in aquatic systems. Recent work entails the adaptive design of urban systems to incorporate coupled ecological processes in response to climate change and demographic shifts. She works closely with the Chicago Legal Clinic to provide technical expertise to solve environmental problems for low-income urban communities and with other NGOs in the Chicago region to develop creative solutions for resource recovery and economic recovery. She was a Senior Science Fellow at the Environmental Law and Policy Center. She is the author of more than 100 scientific papers and lectures widely on energy, climate and environmental issues. Dr. Gray earned her Ph.D. in geography and environmental engineering from the Johns Hopkins University.

Philip K. Hopke is the Bayard D. Clarkson Distinguished Professor Emeritus at Clarkson University and an adjunct professor in the Department of Public Health Sciences at the University of Rochester Medical Center. He was formerly the Director of the Institute and its Center for Air Resources Engineering and Sciences. His research interests are primarily related to particles in the air, including particle formation, sampling and analysis, composition, and origination. His current projects are related to biomass combustion, receptor modeling, ambient monitoring, and nucleation. Dr. Hopke has been elected to membership of the International Statistics Institute and he is a fellow of the American Association for the Advancement of Sciences. He is also a fellow of the American Association for Aerosol Research where he has served in various roles, including as president, vice president, and as a member of the board of directors. Dr. Hopke is a member of the American Institute of Chemical Engineers, the International Society of Exposure Science, and the International Society of Indoor Air Quality and Climate, among others. He has served as a member of the U.S. Environmental Protection Agency Advisory Council on Clean Air Act Compliance Analysis and as a member of several Academies committees. Most recently he was a member of the NRC Committee on Strengthening the U.S. EPA Laboratory Enterprise the U.S. Environmental Protection Agency Laboratory Enterprise: Phase 1 – Priority Needs, Guiding Principles, and Overall Goals and the Committee to Develop a Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials. He is a member of the Board on Environmental Studies and Toxicology. Dr. Hopke received his Ph.D. in chemistry from Princeton University.

Kimberly L. Jones is a professor and chair of the Department of Civil and Environmental Engineering at Howard University. She previously worked as an associate and assistant professor in that department from 1996 to 2009. Dr. Jones' research interests include developing membrane processes for environmental applications, physical-chemical processes for water and wastewater treatment, remediation of emerging contaminants, drinking water quality, and environmental nanotechnology. Dr. Jones currently serves on the Science Advisory Board of the U.S. Environmental Protection Agency, and as chair of the Drinking Water Committee of the Science Advisory Board. She has served on the National Academies Water Science and Technology Board, and the Board of Association of Environmental Engineering and Science Professors, where she was Secretary of the Board. She received a Ph.D. in environmental engineering from the Johns Hopkins University.

Harold A. Mooney (NAS) is the Paul S. Achilles Professor, Emeritus, in Environmental Biology at Stanford University. His research focuses on global change biology. Dr. Mooney is the former Chair of the DIVERSITAS Scientific Committee as well as the Global Invasive Species Program. He also served on several NRC committees, including serving as chair of the Committee to Review EPA's Research Grants Program. Dr. Mooney is a member of the National Academy of Sciences, World Academy of Sciences, and American Philosophical Society. He is a fellow of the American Academy of Arts and Sciences, foreign member of the Russian Academy of Sciences, and honorary member of the British Ecological Society. He was the 1990 recipient of the ECI Prize in terrestrial ecology. He has received the Max Planck Research Award in biosciences (1992; together with Ernst-Detlef Schulze) and been given the Eminent Ecologist Award for 1996 by Ecological Society of America. He has received the Ramon Margalef Prize in Ecology, BBVA Prize in Conservation Biology, Blue Planet Prize, Volvo Environment Prize, and Tyler Prize for Environmental Achievement. He has published extensively in physiological, ecosystem and global change ecology. He has served as Chair of the U.S. Global Change Committee, Secretary General of the International Council for Science, President of the Ecological Society of America, and President of the American Institute of Biology. He was Scientific Panel Co-Chair for the Millennium Ecosystem Assessment. Dr. Mooney earned his Ph.D. in biology from Duke University.

Martin A. Philbert (NAM) is a professor of toxicology and dean of the School of Public Health at the University of Michigan. He became dean on January 1, 2011, having previously served as senior associate dean for research at the school since 2004. He arrived at UM in 1995 from Rutgers' Neurotoxicology Laboratories, where he was a research assistant professor. He has maintained a continuously federally funded portfolio of basic research activities throughout his career. Most recently his work has been funded by the National Institutes of Health, the Department of Air Force, and the National Cancer Institute. At the national level, he is recognized for his work in neurotoxicology and experimental neuropathology. Dr. Philbert was elected to the National Academy of Medicine in 2012. He is the author of numerous research publications in top peer-reviewed journals, and one book. Active research activities include experimental neuropathology, nitrocompound-induced encephalopathies, mitochondrial mechanisms in non-neuronal cell death, development of Nano-Optical Chemical Systems for in vivo physiology, and nanostructure-based imaging and treatment of tumors of malignant gliomas. He received a Ph.D. in neurochemistry and experimental neuropathology from the University of London.

Joshua M. Sharfstein (NAM) is the Associate Dean for Public Health Practice and Training and Professor of the Practice at the Johns Hopkins University. He oversees the Office of Public Health Practice and Training, the General Preventive Medicine Residency and major practice activities, including collaboration with public health agencies. He also holds a faculty appointment in the Department of Health Policy and Management. Previously, he served as secretary of the Maryland Department of Health and Mental Hygiene, the Principal Deputy Commissioner of the U.S. Food and Drug Administration, Commissioner of Health for Baltimore City, and health policy advisor for Congressman Henry A. Waxman. He serves as a member of the National Academies Board on Population Health and Public Health Practice. Dr. Sharfstein received his M.D. from Harvard Medical School.

Mitchell J. Small is the H. John Heinz III Professor of Environmental Engineering at Carnegie Mellon University. Dr. Small's research involves mathematical modeling of environmental systems, environmental statistics, risk assessment, and decision support. Current projects include the design and evaluation of leak detection at geologic CO_2 sequestration sites and shale gas extraction wells; the value of scientific information for conflict resolution among stakeholders with different values and beliefs; and the development of decision support tools for water, energy and ecosystem management. He has published more than 200 manuscripts in peer reviewed journals (160), books and conference proceedings. Dr. Small has served as a member of the U.S. EPA Science Advisory Board (SAB) and has been a member of nine National Academies committees, most recently as chair of the Committee on Risk Management and Governance Issues in Shale Gas Extraction. He is a Fellow of the Society for Risk Analysis and served as an associate editor for the journal Environmental Science & Technology (1995-2011), where he helped to initiate the policy analysis section of the journal. Dr. Small received a Ph.D. in environmental and water resources engineering from the University of Michigan.

Clifford P. Weisel is a professor at the Rutgers University and acting director of the Exposure Science Division of the university's Environmental and Occupational Health Sciences Institute. He also is director of the Doctoral Degree Program in Exposure Science offered by Rutgers University. The focus of Dr. Weisel's research is on understanding exposure to chemical agents, with an emphasis on multi-route exposures to environmental contaminants, the association between exposure and adverse health effects, utilization of sensors for continuous exposure measurement, and development and application of biomarkers of exposure, including metabolomics. He has examined the relationship among indoor, outdoor and personal exposures to air pollutants, documented the importance of inhalation and dermal exposure to contaminants, characterized exposures within the transportation sector, and examined exposure and health issues related to disinfection by-products in water. He is a past president and treasurer of the International Society of Exposure Science and has served on numerous international and national advisory committees, workshops and advisory review panels for NAS, EPA, NIEHS, CDC, state governmental, environmental groups and private industry. He served as associate editor of the Journal of Exposure Science and Environmental Epidemiology. Dr. Weisel has authored or co-authored more than 100 peer-reviewed publications and book chapters; he co-authored with Dr. Paul Lioy the book Exposure Science: Basic Principles and Applications. He received a M.S. degree and Ph.D. in Analytical Chemistry and Chemical Oceanography, respectively, from the University of Rhode Island.

Appendix B

Summary of the Previous Reviews of the Science to Achieve Results Program

TABLE B-1 Summary of Reviews of the STAR Program

Review	Type of Review	Brief summary	EPA's Responses
U.S. Government Accountability Office (U.S. Congress). 2000. Environmental Research: STAR Grants Focus on Agency Priorities, but Management Enhancements Are Possible. Washington, DC.	Programmatic	The review recommended that: • EPA develops program criteria to evaluate the "effectiveness" of each type of STAR grant. EPA to improve "communication and dissemination" of STAR research results within and outside EPA among many of its public and private stakeholders.	• EPA's Science Advisory Board (SAB) agreed to review the effectiveness of the results of STAR research by individual research area. EPA contracted with the National Academy of Sciences (NAS) to evaluate the STAR program on a broad scale and then by specific issues. • EPA has: (1) developed a system to collect, review, and post abstracts and project reports; (2) established a process to improve the likelihood of timely submission of final reports.
EPA's Science Advisory Board and the Office of Research and Development's Board of Scientific Councilors. 2000. A Joint SAB/BOSC Report: Review of the Science to Achieve Results (STAR). Washington, DC: EPA.	Scientific and programmatic review	This review gave EPA an "overall favorable assessment," but recommended that: • EPA improve "information transfer." • EPA provide additional information in RFAs on research goals and objectives; "relevancy criteria", and accelerate availability of STAR results. • EPA include the ten regional offices into all facets of the STAR process. • The STAR program periodically review its research portfolio for its utility and applicability to EPA's mission. • The STAR program expand its partnership with other federal and international agencies as well as private foundations. • EPA to look into the evaluation of STAR program results by outside "qualified, highly respected, and independent organization."	• No response provided
EPA Office of Inspector General Report, 2003. STAR Fellowship Program Needs to Place Emphasis on Measuring Results.	Programmatic review	Here, the focus was narrow and on measuring the results of STAR's fellowship program. EPA was asked to: • Maintain necessary data on fellowship applicants and recipients, including collection, maintenance, and review of "demographic composition of the STAR applicant pool and the fellows selected, and to adjust outreach efforts accordingly". • Improve internal evaluation, performance measures, and applicant data.	• Agency agreed to establish Performance Measures, tracking the fellows after completion of the program,. EPA prepared an action plan, including action officials and due dates for each recommendation. However, EPA did not agree with comments on diversity and need for outreach. ORD agreed to conduct internal evaluations, establish performance measures, and collect data.
Office of Research and Development's Board of Scientific Councilors. 2009. Review of ORD's National Center for Environmental Research (NCER) Letter Report.	Programmatic review	Here, the focus was narrow and on measuring the results of EPA's greater research opportunities (GRO) fellowship program. • BOSC recommended that EPA consider eliminating the GRO fellowship programs (graduate and undergraduate).	• EPA responded by eliminating the GRO graduate program but continuing the undergraduate GRO fellowships.

EPA's Science Advisory Board and the Office of Research and Development's Board of Scientific Councilors. 2011. Office of Research and Development (ORD) New Strategic Research Directions. Washington, DC.	Programmatic review	This report reviewed ORD as a whole following ORD's 2010 reorganization. It recommended that ORD incorporate the principles of sustainability into the six newly named research areas and that social, behavioral, and decision sciences be emphasized within ORD/ support ORD's technical and innovation goals.	• No responses specific to the STAR program
EPA's Science Advisory Board and the Office of Research and Development's Board of Scientific Councilors. 2012. Implementation of ORD Strategic Research Plans.	Programmatic Review	This report reviewed ORD as a whole, and recommended that ORD: • Provide a comprehensive mapping of project to goals for the six new program areas. • Balance immediate program needs and emerging issues through a "structured approach"	• No responses specific to the STAR program
U.S. Environmental Protection Agency. 2013. EPA Needs to Improve STAR Grant Oversight. Edited by Office of the Inspector General. Washington, DC.	Programmatic Review	Reviewed the STAR grant oversight process and recommend that EPA: • Improve training of project officers to improve baseline monitoring, ensure that reports are accurately completed, enforcing the terms and conditions that allow funds to be withheld, if reports are missing/late. • Improve accounting of costs and budgets as well as improve project officer's understanding of research misconduct reporting requirements.	• ORD will provide all STAR grant project officers with training on the performance of baseline monitoring. • ORD drafted standard operating procedures for steps to be taken when annual progress reports are late, including when to pursue withholding grant funds • ORD was to revise its guidance pertaining to annual report reviews and publications with proper acknowledgements and disclaimers. ORD was to include a condition that payments may be withheld when reports are missing or late.
(EPA's Science Advisory Board and the Office of Research and Development's Board of Scientific Councilors 2016)	Programmatic Review	This review was of EPA ORD's entire research program. Recommendations include that EPA should: • Develop measures of success for outputs and outcomes for each national program. • Further develop and enhance efforts in research synthesis and translation. The Agency might benefit from identifying or training the appropriate people best suited to synthesize or translate research work and provides rewards and incentives for doing so as translational work does not necessarily lend itself to peer-reviewed publications, yet the benefits for policy makers and the public can be substantial. • Continue to nurture and expand cross-program and transdisciplinary integration to increase efficiencies and synergies. • Maintain alignment between research that is focused on short-term goals and long term objectives.	

(Continued)

TABLE B-1 Continued

Review	Type of Review	Brief summary	EPA's Responses
U.S. Environmental Protection Agency. OIG 2016. EPA Offices Are Aware of the Agency's Science to Achieve Results Program, but Challenges Remain in Measuring and Internally Communicating Research Results That Advance the Agency's Mission. Edited by Office of the Inspector General. Washington, DC.	Programmatic Review	This review recommended that EPA: 1. ORD NCER should develop and implement SOPs to improve internal communications under ORD's new matrix structure of STAR grant research results to EPA program and regional offices. The procedures should a) Ensure that the STAR grant public website is up to date. b) Revise the NCER Project Officer Manual (or develop a more dynamic tool) for communicating grant results. c) Clarify and define roles and responsibilities for communicating research results. 2. Create procedures for developing RFAs to ensure program office input is considered in the RFA development process. 3. Create procedures for conducting the relevancy reviews to ensure that program office input is more consistently and transparently considered in the grant selection process (to the extent permitted by the FGCAA and EPA Order 5700.1). 4. Develop goals and objectives for the STAR program 5. Establish a means to capture and report out on how completed STAR grants have met their performance goals and provide incidental research support to program offices.	1. Develop and implement procedures to improve communications with the EPA's program offices regarding STAR research results. a) NCER will establish an SOP to assure that STAR grant updates are provided in a timely manner, as well as a method for identifying missing reports. NCER will coordinate and work with all involved staff leads (NCER, ORD, NPD) including communications, MIs, and POs to identify best practices to fulfill needs for communicating grant results and developing an SOP for grant research results communications. 2. Working with ORD NPDs, NCER will update the current written SOP to formalize the current standard practice of RFA development that includes program and regional office input and assistance. 3. NCER is finalizing a written SOP for its relevancy reviews that includes information regarding how relevancy review information is to be incorporated into the grant selection process. The SOP will provide guidance on information to be routinely shared with reviewers including limitations on the use of grants per FGCAA and EPA Order 5700.1, as well as explaining how relevance review results will be incorporated into the grant selection process. 4. NCER will clarify the goals and objectives for the STAR grants that can be consistently used for various audiences. 5. NCER, in collaboration with the NPDs, will establish a new SOP (including a communications plan) for documenting ORD L/C/O, program office, and regional office participation in the identification of RFA topics (and funding decisions) to assist EPA in advancing its mission; how individual grants are expected to fulfill the purpose of the RFA; and ultimately presenting how the funded grants met the RFA and individual grant performance measures.

Appendix C

Assignment of Science to Achieve Results Request for Applications to Scientific Domains

RFA	Year	Categories
2003	Centers for Children's Environmental Health and Disease Prevention Research	Human Exposure and Health Effects Toxicology
2003	Consequences of Global Change for Air Quality: Spatial Patterns in Air Pollution Emissions	Human Exposure and Health Effects Climate Sciences Atmospheric Sciences
2003	Development of High-Throughput Screening Approaches for Prioritizing Chemicals for the Endocrine Disruptors Screening Program	Molecular Biology and Biotechnology Toxicology
2003	Development of Watershed Classification Systems for Diagnosis of Biological Impairment in Watersheds and Their Receiving Water Bodies	Hydrology and Water Resources Innovative Communication and Participation Innovative Risk Management Innovative Technologies Systems Modeling and Decision Support Technology for Environmental Monitoring and Data Analysis
2003	Epidemiologic Research on Health Effects of Long-Term Exposure to Ambient Particulate Matter and Other Air Pollutants	Human Exposure and Health Effects Toxicology
2003	Exploratory Research to Anticipate Future Environmental Issues: Impacts of Manufactured Nanomaterials on Human Health and the Environment	Human Exposure and Health Effects Technology for Environmental Monitoring and Data Analysis Toxicology
2003	HSRC - TTAB Brownfields	Innovative Risk Management Mathematics, Statistics, and Computer Science Risk Analysis Systems Modeling and Decision Support
2003	Market Mechanisms and Incentives for Environmental Management	Environmental Economics Innovative Risk Management Systems Modeling and Decision Support
2003	Measurement, Modeling, and Analysis Methods for Airborne Carbonaceous Fine Particulate Matter ($PM_{2.5}$)	Innovative Risk Management Risk Analysis Systems Modeling and Decision Support
2003	Microbial Risk in Drinking Water	Hydrology and Water Resources Innovative Risk Management Risk Analysis Systems Modeling and Decision Support Technology for Environmental Monitoring and Data Analysis
2003	New Technologies for the Environment (NTE)	Innovative Technologies Technology for Environmental Monitoring and Data Analysis
2003	Technology for a Sustainable Environment	Innovative Technologies Sustainable Energy Technology for Environmental Monitoring and Data Analysis

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RFA	Year	Categories
2003	The Role of Air Pollutants in Cardiovascular Disease	Human Exposure and Health Effects Toxicology
2003	Valuation for Environmental Policy	Environmental Economics
2004	Application of Biomarkers to Environmental Health and Risk Assessment	Human Exposure and Health Effects Innovative Risk Management Risk Analysis Technology for Environmental Monitoring and Data Analysis Toxicology
2004	Computational Toxicology and Endocrine Disruptors: Use of Systems Biology in Hazard Identification and Risk Assessment	Mathematics, Statistics, and Computer Science Risk Analysis Systems Modeling and Decision Support Technology for Environmental Monitoring and Data Analysis Toxicology
2004	Computational Toxicology: Environmental Bioinformatics Research Center	Mathematics, Statistics, and Computer Science Systems Modeling and Decision Support Toxicology
2004	Corporate Environmental Behavior and the Effectiveness of Government Interventions	Environmental Economics Innovative Risk Management Risk Analysis
2004	Development and Characterization of Biological Systems for Studying Low Dose Effects of Endocrine Disrupting Chemicals	Molecular Biology and Biotechnology Toxicology
2004	DHS-EPA Cooperative Center of Excellence on the Methods and Science to Conduct Microbial Risk Assessment in Support of Homeland Security Objectives	Innovative Risk Management Risk Analysis Technology for Environmental Monitoring and Data Analysis
2004	Early Indicators of Environmentally Induced Disease	Technology for Environmental Monitoring and Data Analysis Toxicology
2004	Ecology and Oceanography of Harmful Algal Blooms	Innovative Risk Management Risk Analysis Ecology
2004	Effects of Climate Change on Ecosystem Services Provided by Coral Reefs and Tidal Marshes	Hydrology and Water Resources Climate Sciences Ecology
2004	Environmental Statistics Research: Novel Analyses of Human Exposure Related Data	Human Exposure and Health Effects Mathematics, Statistics, and Computer Science
2004	Exploratory Research: Understanding Ecological Thresholds In Aquatic Systems Through Retrospective Analysis	Innovative Risk Management Risk Analysis Technology for Environmental Monitoring and Data Analysis Ecology
2004	Fire, Climate, and Air Quality	Human Exposure and Health Effects Climate Science
2004	Greater Research Opportunities: Research in Nanoscale Science Engineering and Technology	Human Exposure and Health Effects Technology for Environmental Monitoring and Data Analysis Toxicology
2004	Particulate Matter Research Centers	Innovative Risk Management Risk Analysis Toxicology

2004	Regional Development, Population Trend, and Technology Change Impacts on Future Air Pollution Emissions	Innovative Technologies Systems Modeling and Decision Support
2004	Source Apportionment of Particulate Matter	Innovative Risk Management Risk Analysis
2004	Valuation for Environmental Policy	Environmental Economics
2005	Centers for Children's Environmental Health and Disease Prevention Research	Human Exposure and Health Effects Toxicology
2005	Continuous Measurement Methods for Particulate Matter Composition	Technology for Environmental Monitoring and Data Analysis Atmospheric Sciences
2005	Decision Support Systems Involving Climate Change and Public Health	Human Exposure and Health Effects Systems Modeling and Decision Support Climate Sciences
2005	Development and Evaluation of Innovative Approaches for the Quantitative Assessment of Pathogens in Drinking Water	Innovative Risk Management Innovative Technologies Technology for Environmental Monitoring and Data Analysis
2005	Environmental Behavior and Decision-making: Determining the Effectiveness of Environmental Information Disclosure and Provision	Innovative Communication and Participation Innovative Communication and Participation
2005	Exploratory Research: Nanotechnology Research Grants Investigating Environmental and Human Health Effects of Manufactured Nanomaterials: A Joint Research Solicitation – EPA, NSF, NIOSH	Human Exposure and Health Effects Technology for Environmental Monitoring and Data Analysis Toxicology
2005	Exposure Measurement Tools for Endocrine Disrupting Chemicals in Mixtures	Human Exposure and Health Effects Technology for Environmental Monitoring and Data Analysis
2005	Implications of Tropospheric Air Pollution for Surface UV Exposures	Human Exposure and Health Effects Atmospheric Sciences
2005	Nonlinear Responses to Global Change in Linked Aquatic and Terrestrial Ecosystems and Effects of Multiple Factors on Terrestrial Ecosystems: A Joint Research Solicitation-EPA, DOE	Atmospheric Sciences Ecology
2005	The Impact of Climate Change & Variability on Human Health	Human Exposure and Health Effects Climate Sciences
2005	Valuation for Environmental Policy	Environmental Economics
2006	Biotechnology: Potential Allergenicity of Genetically Engineered Foods	Molecular Biology and Biotechnology Toxicology
2006	Collaborative Science and Technology Network For Sustainability	Innovative Technologies Innovative Communication and Participation
2006	Consequences of Global Change For Air Quality	Climate Sciences Atmospheric Sciences
2006	Development of Environmental Health Outcome Indicators	Human Exposure and Health Effects Risk Analysis Technology for Environmental Monitoring and Data Analysis
2006	Ecology and Oceanography of Harmful Algal Blooms	Hydrology and Water Resources Ecology
2006	Exploratory Research: Nanotechnology Research Grants Investigating Environmental and Human Health Effects of Manufactured Nanomaterials: a Joint Research Solicitation – EPA, NSF, NIOSH, NIEHS	Human Exposure and Health Effects Molecular Biology and Biotechnology Technology for Environmental Monitoring and Data Analysis Toxicology

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RFA	Year	Categories
2006	Fate and Effects of Hormones in Waste from Concentrated Animal Feeding Operations (CAFOS)	Hydrology and Water Resources Risk Analysis
2006	Interpretation of Biomarkers Using Physiologically Based Pharmacokinetic Modeling	Human Exposure and Health Effects Technology for Environmental Monitoring and Data Analysis
2006	Market Mechanisms and Incentives: Case Studies and Experimental Testbeds for New Environmental Trading Programs	Environmental Economics
2006	Methodological Advances in Benefit Transfer Methods	Environmental Economics
2006	Sources, Composition, and Health Effects of Coarse Particulate Matter	Human Exposure and Health Effects Atmospheric Sciences
2006	Uncertainty Analyses of Models in Integrated Environmental Assessments	Risk Analysis Systems Modeling and Decision Support
2007	An Interdisciplinary Approach to Examining The Links Between Social Stressors, Biodiversity and Human Health	Human Behavioral Studies Human Exposure and Health Effects
2007	Center for the Environmental Implications of Nanotechnology (CEIN) (in conjunction with NSF)	Human Exposure and Health Effects Toxicology
2007	Computational Toxicology Centers: Development of Predictive Environmental and Biomedical Computer-Based Simulations and Models	Mathematics, Statistics, and Computer Science Systems Modeling and Decision Support Toxicology
2007	Development and Evaluation of Innovative Approaches for the Quantitative Assessment of Pathogens and Cyanobacteria and Their Toxins in Drinking Water	Innovative Technologies Mathematics, Statistics, and Computer Science
2007	Development of Environmental Health Outcome Indicators	Human Exposure and Health Effects
2007	Ecological Impacts from the Interactions of Climate Change, Land Use Change and Invasive Species: A Joint Research Solicitation - EPA, USDA	Systems Modeling and Decision Support Climate Sciences Ecology
2007	Exploratory Investigations in Food Allergy	Human Exposure and Health Effects Molecular Biology and Biotechnology
2007	Exploratory Research: Nanotechnology Research Grants Investigating Fate, Transport, Transformation, and Exposure of Engineered Nanomaterials: A Joint Research Solicitation – EPA, NSF, & DOE	Human Exposure and Health Effects Hydrology and Water Resources Physics and Chemistry
2007	Innovative Approaches to Particulate Matter Health, Composition, and Source Questions	Human Exposure and Health Effects Risk Analysis Toxicology Atmospheric Sciences
2007	Interpretation of Biomarkers Using Physiologically Based Pharmacokinetic Modeling	Human Exposure and Health Effects Toxicology
2007	Issues in Tribal Environmental Research and Health Promotion: Novel Approaches for Assessing and Managing Cumulative Risks and Impacts of Global Climate Change	Human Exposure and Health Effects Innovative Communication and Participation Risk Analysis Climate Sciences
2007	Manufactured Nanomaterials: Physico-chemical Principles of Biocompatibility and Toxicity	Molecular Biology and Biotechnology Toxicology
2007	Sources and Atmospheric Formation of Organic Particulate Matter	Atmospheric Sciences

Appendix C

2008	Adaptation for Future Air Quality Analysis and Decision Support Tools in Light of Global Change Impacts and Mitigation	Innovative Risk Management Systems Modeling and Decision Support
2008	Climate Change and Allergic Airway Disease	Molecular Biology and Biotechnology Toxicology Climate Sciences
2008	Consequences of Global Change for Water Quality	Hydrology and Water Resources Systems Modeling and Decision Support
2008	Forecasting Ecosystem Services from Wetland Condition Analyses	Hydrology and Water Resources Ecology
2008	Health Effects of Near-Roadway Exposures to Air Pollution	Human Exposure and Health Effects Toxicology
2008	Innovative and Integrative Approaches for Advancing Public Health Protection Through Water Infrastructure Sustainability	Human Exposure and Health Effects Hydrology and Water Resources
2009	Advancing Public Health Protection through Water Infrastructure Sustainability	Human Exposure and Health Effects Hydrology and Water Resources
2009	Approaches to Assessing Potential Food Allergy from Genetically Engineered Plants	Human Exposure and Health Effects Molecular Biology and Biotechnology
2009	Children's Environmental Health and Disease Prevention Research Centers (with NIEHS)	Human Exposure and Health Effects Innovative Communication and Participation Toxicology
2009	Children's Environmental Health and Disease Prevention Research Centers: Formative Centers (with NIEHS)	Human Exposure and Health Effects Innovative Communication and Participation Toxicology
2009	Clean Air Research Centers	Human Exposure and Health Effects Innovative Communication and Participation Toxicology
2009	Computational Toxicology Research Centers: in vitro and in silico Models of Developmental Toxicity Pathways	Human Exposure and Health Effects Innovative Communication and Participation Mathematics, Statistics, and Computer Science Toxicology
2009	Enhancing Ecosystem Services From Agricultural Lands: Management, Quantification, and Developing Decision Support Tools	Systems Modeling and Decision Support Ecology
2009	Environmental Behavior, Bioavailability and Effects of Manufactured Nanomaterials: Joint US-UK Research Program	Human Exposure and Health Effects Toxicology
2009	Exploring Linkages Between Health Outcomes and Environmental Hazards, Exposures, and Interventions for Public Health Tracking and Risk Management	Human Exposure and Health Effects Innovative Risk Management Risk Analysis
2009	Integrated Design, Modeling, and Monitoring of Geologic Sequestration of Anthropogenic Carbon Dioxide to Safeguard Sources of Drinking Water	Hydrology and Water Resources Systems Modeling and Decision Support Technology for Environmental Monitoring and Data Analysis
2009	Novel Approaches to Improving Air Pollution Emissions Information	Technology for Environmental Monitoring and Data Analysis Atmospheric Sciences
2009	Understanding the Role of Nonchemical Stressors and Developing Analytic Methods for Cumulative Risk Assessments	Risk Analysis Systems Modeling and Decision Support

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RFA	Year	Categories
2010	Black Carbons Role In Global to Local Scale Climate and Air Quality	Climate Sciences Atmospheric Sciences
2010	Computational Toxicology: Biologically-Based Multi-Scale Modeling	Mathematics, Statistics, and Computer Science Molecular Biology and Biotechnology Risk Analysis Toxicology
2010	Exploring New Air Pollution Health Effects Links in Existing Datasets	Human Exposure and Health Effects Atmospheric Sciences
2010	Increasing Scientific Data on the Fate, Transport and Behavior of Engineered Nanomaterials in Selected Environmental and Biological Matrices	Hydrology and Water Resources Systems Modeling and Decision Support
2011	Developing High-Throughput Assays for Predictive Modeling of Reproductive and Developmental Toxicity Modulated Through the Endocrine System or Pertinent Pathways in Humans and Species Relevant to Ecological Risk Assessment	Molecular Biology and Biotechnology Risk Analysis Toxicology Ecology
2011	Developing the Next Generation of Air Quality Measurement Technology	Human Exposure and Health Effects Risk Analysis Technology for Environmental Monitoring and Data Analysis
2011	Dynamic Air Quality Management	Human Exposure and Health Effects Risk Analysis
2011	Environmental Impact and Mitigation of Oil Spills	Environmental Engineering Innovative Technologies
2011	Extreme Event Impacts on Air Quality and Water Quality with a Changing Global Climate	Climate Sciences Atmospheric Sciences
2011	Research and Demonstration of Innovative Drinking Water Treatment Technologies in Small Systems	Hydrology and Water Resources Innovative Technologies
2011	Sustainable Chesapeake: A Collaborative Approach to Urban Stormwater Management	Environmental Engineering Innovative Risk Management
2012	Anthropogenic Influences on Organic Aerosol Formation and Regional Climate Implications	Human Exposure and Health Effects Risk Analysis Climate Sciences
2012	Children's Environmental Health and Disease Prevention Research Centers (with NIEHS)	Human Exposure and Health Effects Innovative Communication and Participation Toxicology
2012	Development and Use of Adverse Outcome Pathways that Predict Adverse Developmental Neurotoxicity	Molecular Biology and Biotechnology Systems Modeling and Decision Support Toxicology
2012	Measurements and Modeling for Quantifying Air Quality and Climatic Impacts of Residential Biomass or Coal Combustion for Cooking, Heating, and Lighting	Human Exposure and Health Effects Innovative Risk Management Risk Analysis Sustainable Energy Technology for Environmental Monitoring and Data Analysis
2012	Performance and Effectiveness of Green Infrastructure Stormwater Management Approaches in the Urban Context: A Philadelphia Case Study	Environmental Engineering Innovative Risk Management
2012	Sustainable Chesapeake: A Community-Based Approach to Stormwater Management Using Green Infrastructure	Environmental Engineering Innovative Risk Management
2013	EPA/NSF Networks for Characterizing Chemical Life Cycle (NCCLCs)	Systems Modeling and Decision Support Physics and Chemistry

2013	Healthy Schools: Environmental Factors, Children's Health and Performance, and Sustainable Building Practices	Human Exposure and Health Effects Innovative Risk Management Innovative Technologies Risk Analysis Toxicology
2013	National Centers for Innovation in Small Drinking Water Systems	Human Exposure and Health Effects Innovative Technologies
2013	New Methods in 21st Century Exposure Science	Human Exposure and Health Effects Innovative Technologies Risk Analysis Technology for Environmental Monitoring and Data Analysis
2013	Organotypic Culture Models for Predictive Toxicology Center	Molecular Biology and Biotechnology Risk Analysis Toxicology
2013	Science for Sustainable and Healthy Tribes	Human Exposure and Health Effects Innovative Communication and Participation
2013	Susceptibility and Variability in Human Response to Chemical Exposure	Human Exposure and Health Effects Risk Analysis Toxicology
2014	Air Pollution Monitoring for Communities	Human Exposure and Health Effects Innovative Communication and Participation Risk Analysis Technology for Environmental Monitoring and Data Analysis
2014	Air, Climate and Energy (ACE) Centers: Science Supporting Solutions	Innovative Risk Management Systems Modeling and Decision Support Climate Sciences Atmospheric Sciences
2014	Human and Ecological Health Impacts Associated with Water Reuse and Conservation Practices	Human Exposure and Health Effects Hydrology and Water Resources Risk Analysis Ecology
2014	Indoor Air and Climate Change	Human Exposure and Health Effects Climate Sciences
2014	National Center for Sustainable Water Infrastructure Modeling Research	Hydrology and Water Resources Innovative Risk Management Risk Analysis Systems Modeling and Decision Support
2014	Particulate Matter and Related Pollutants in a Changing World	Risk Analysis Atmospheric Sciences
2014	Systems-Based Research for Evaluating Ecological Impacts of Manufactured Chemicals	Innovative Risk Management Systems Modeling and Decision Support Toxicology Ecology
2015	Water Quality Benefits	Environmental Engineering Hydrology and Water Resources Innovative Risk Management Risk Analysis

Appendix D

Assignment of Highly Cited Science to Achieve Results–Funded Papers to Scientific Domains

Paper	STAR Funding	Scientific Domain
Alam, M.G.M., E.T. Snow, and A. Tanaka. 2003. Arsenic and heavy metal contamination of rice, pulses and vegetables grown in Samta village, Bangladesh. Pp. 103-114 in Arsenic Exposure and Health Effects 5, W.R. Chappell, C.O. Abernathy, R.L. Calderon, and D.J. Thomas, eds. Amsterdam: Elsevier.	Grant	Human exposure and health effects
Anton, W.R.Q, G. Deltas, and M. Khanna. 2004. Incentives for environmental self-regulation and implications for environmental performance. J. Environ. Econ. Manage. 48(1):632-654.	Grant	Environmental economics Human behavioral studies Innovative communication and participation
Bisceglia, K.J., T.Y. Jim, M. Coelhan, E.J. Bouwer, and A.L. Roberts. 2010. Trace determination of pharmaceuticals and other wastewater-derived micropollutants by solid phase extraction and gas chromatography/mass spectrometry. J. Chromatogr. A 1217(4):558-564.	Grant and fellowship	Chemistry and physics Ecology Human exposure and health effects Technology for environmental monitoring and data analysis
Borsuk, M.E., C.A. Stow, and K.H. Reckhow. 2004. A Bayesian network of eutrophication models for synthesis, prediction, and uncertainty analysis. Ecol. Model. 173(2):219-239.	Fellowship	Mathematics, statistics, and computer science Systems modeling and decision support
Cao, J., D. Elliott, and W. Zhang. 2005. Perchlorate reduction by nanoscale iron particles. J. Nanopart. Res. 7(4-5):499-506.	Grant	Process technology Environmental engineering Innovative technologies
Carlton, A.G., B.J. Turpin, H.J. Lim, K.E. Altieri, and S. Seitzinger. 2006. Link between isoprene and secondary organic aerosol (SOA): Pyruvic acid oxidation yields low volatility organic acids in clouds. Geophys. Res. Lett. 33(6).	Grant	Atmospheric sciences
Carlton, A.G., B.J. Turpin, K.E. Altieri, S. Seitzinger, A. Reff, H.J. Lim, and B. Ervens. 2007. Atmospheric oxalic acid and SOA production from glyoxal: Results of aqueous photooxidation experiments. Atmos. Environ. 41(35):7588-7602.	Grant	Atmospheric sciences
Cason, T.N., and L. Gangadharan. 2004. Auction design for voluntary conservation programs. Am. J. Agric. Econ. 86(5):1211-1217.	Grant	Environmental economics Human behavioral studies Innovative risk management
Craft, C., and J. Sacco. 2003. Long-term succession of benthic infauna communities on constructed Spartina alterniflora marshes. MEPS 257:45-58.	Grant	Hydrology and water resources Ecology

Craft, C., S. Broome, and C. Campbell. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restor. Ecol. 10(2):248-258.	Grant	Ecology Hydrology and water resources
Desai, K., K. Kit, J. Li, P.M. Davidson, S. Zivanovic, and H. Meyer. 2009. Nanofibrous chitosan non-wovens for filtration applications. Polymer 50(15):3661-3669.	Grant	Process technology Environmental engineering Innovative technologies
Eatough, D.J., R.W. Long, W.K. Modey, and N.L. Eatough. 2003. Semi-volatile secondary organic aerosol in urban atmospheres: Meeting a measurement challenge. Atmos. Environ. 37(9):1277-1292.	Grant	Chemistry and physics Atmospheric sciences Technology for environmental monitoring and data analysis
Eggleston, P.A., A. Butz, C. Rand, J. Curtin-Brosnan, S. Kanchanaraksa, L. Swartz, P. Breysse, T. Buckley, G. Diette, B. Merriman, and J.A. Krishnan. 2005. Home environmental intervention in inner-city asthma: A randomized controlled clinical trial. Ann. Allergy Asthma Immunol. 95(6):518-524.	Grant	Human exposure and health effects Innovative risk management
Engler, A.C., H.I. Lee, and P.T. Hammond. 2009. Highly efficient "grafting onto" a polypeptide backbone using click chemistry. Angew. Chem. Int. Ed. 48(49):9334-9338.	Fellowship	Molecular biology and biotechnology Chemistry and physics Process technology
Fourches, D., E. Muratov, and A. Tropsha. 2010. Trust, but verify: On the importance of chemical structure curation in cheminformatics and QSAR modeling research. J. Chem. Inf. Model. 50(7):1189-1204.	Grant	Mathematics, statistics, and computer science Toxicology
Groffman, P.M., J.S. Baron, T. Blett, A.J. Gold, I. Goodman, L.H. Gunderson, B.M. Levinson, M.A. Palmer, H.W. Paerl, G.D. Peterson, N. LeRoy Poff, D.W. Rejeski, J.F. Reynolds, M.G. Turner, K.C. Weathers, and J. Wiens. 2006. Ecological thresholds: The key to successful environmental management or an important concept with no practical application? Ecosystems 9(1):1-13.	Grant	Life sciences Ecology Risk analysis
Gunningham, N.A., D. Thornton, and R.A. Kagan. 2005. Motivating management: Corporate compliance in environmental protection. Law Policy 27(2):289-316.	Grant	Human behavioral studies Innovative communication and participation Innovative risk management
Henry, T.B., J.W. Kwon, K.L. Armbrust, and M.C. Black. 2004. Acute and chronic toxicity of five selective serotonin reuptake inhibitors in Ceriodaphnia dubia. Environ. Toxicol. Chem. 23(9):2229-2233.	Grant	Ecology Risk analysis
Jang, M., N.M. Czoschke, S. Lee, and R.M. Kamens. 2002. Heterogeneous atmospheric aerosol production by acid-catalyzed particle-phase reactions. Science 298(5594):814-817.	Grant	Atmospheric sciences Climate sciences
Jantz, C.A., S.J. Goetz, D. Donato, and P. Claggett. 2010. Designing and implementing a regional urban modeling system using the SLEUTH cellular urban model. Comput. Environ. Urban Syst. 34(1):1-16.	Grant	Hydrology and water resources Ecology Climate sciences Technology for environmental monitoring and data analysis

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Paper	STAR Funding	Scientific Domain
Judy, J.D., J.M. Unrine, and P.M. Bertsch. 2010. Evidence for biomagnification of gold nanoparticles within a terrestrial food chain. Environ. Sci. Technol. 45(2):776-781.	Grant	Ecology Environmental engineering Risk analysis
Karnik, B.S., S.H.R. Davies, K.C. Chen, D.R. Jaglowski, M.J. Baumann, and S.J. Masten. 2005. Effects of ozonation on the permeate flux of nanocrystalline ceramic membranes. Water Res. 39(4):728-734.	Grant	Environmental engineering Innovative technologies
Kasprzyk, J.R., S. Nataraj, P.M. Reed, and R.J. Lempert. 2013. Many objective robust decision making for complex environmental systems undergoing change. Environ. Model. Softw. 42:55-71.	Fellowship	Systems modeling and decision support Hydrology and water resources
Keeler, B.L., S. Polasky, K.A. Brauman, K.A. Johnson, J.C. Finlay, A. O'Neill, K. Kovacs, and B. Dalzell. 2012. Linking water quality and well-being for improved assessment and valuation of ecosystem services. Proc. Natl. Acad. Sci. 109(45):18619-18624.	Fellowship	Hydrology and water resources Environmental economics
Kercher, S.M., C.B. Frieswyk, and J.B. Zedler. 2003. Effects of sampling teams and estimation methods on the assessment of plant cover. J. Veg. Sci. 14(6):899-906.	Grant	Ecology Technology for environmental monitoring and data analysis
Kim, E., and P.K. Hopke. 2004. Comparison between conditional probability function and nonparametric regression for fine particle source directions. Atmos. Environ. 38(28):4667-4673.	Grant	Mathematics, statistics, and computer science Atmospheric sciences
Kindermann, G., M. Obersteiner, B. Sohngen, J. Sathaye, K. Andrasko, E. Rametsteiner, B. Schlamadinger, S. Wunder, and R. Beach. 2008. Global cost estimates of reducing carbon emissions through avoided deforestation. Proc. Natl. Acad. Sci. 105(30):10302-10307.	Grant	Ecology Climate sciences Environmental economics Innovative risk management
Knowlton, K., B. Lynn, R.A. Goldberg, C. Rosenzweig, C. Hogrefe, J.K. Rosenthal, and P.L. Kinney. 2007. Projecting heat-related mortality impacts under a changing climate in the New York City region. Am. J. Public Health 97(11):2028-2034.	Grant	Climate sciences Human Exposure and Health Effects Risk analysis
Law, B.E., D. Turner, J. Campbell, O.J. Sun, S. Van Tuyl, W.D. Ritts, and W.B. Cohen. 2004. Disturbance and climate effects on carbon stocks and fluxes across western Oregon USA. Global Change Biol. 10(9):1429-1444.	Grant	Ecology Climate sciences Systems modeling and decision support Technology for environmental monitoring and data analysis
Leach, W.D., N.W. Pelkey, and P.A. Sabatier. 2002. Stakeholder partnerships as collaborative policymaking: Evaluation criteria applied to watershed management in California and Washington. J. Pol. Anal. Manage. 21(4):645-670.	Grant	Innovative communication and participation
Lee, S.W., and W.M. Sigmund. 2003. Formation of anatase TiO 2 nanoparticles on carbon nanotubes. Chem. Commun. 6:780-781.	Grant	Chemistry and physics Process technology Environmental engineering Innovative technologies

Appendix D

Lu, C., K. Toepel, R. Irish, R.A. Fenske, D.B. Barr, and R. Bravo. 2006a. Organic diets significantly lower children's dietary exposure to organophosphorus pesticides. Environ. Health Perspect. 114(2):260-263.	Grant	Human exposure and health effects Risk analysis Innovative risk management
Lu, C., D.B. Barr, M. Pearson, S. Bartell, and R. Bravo. 2006b. A longitudinal approach to assessing urban and suburban children's exposure to pyrethroid pesticides. Environ. Health Perspect. 114(9):1419-1423.	Grant	Human exposure and health effects Human behavioral studies Risk analysis
Lu, C., D.B. Barr, M.A. Pearson, and L.A. Waller. 2008. Dietary intake and its contribution to longitudinal organophosphorus pesticide exposure in urban/suburban children. Environ. Health Perspect. 116(4):537-542.	Grant	Human exposure and health effects Risk analysis Innovative risk management
Mauderly, J.L., and J.M. Samet. 2009. Is there evidence for synergy among air pollutants in causing health effects?" Environ. Health Perspect. 117(1):1-6.	Grant	Toxicology Human exposure and health effects Risk analysis
Murphy, M.A., J.S. Evans, and A. Storfer. 2010. Quantifying Bufo boreas connectivity in Yellowstone National Park with landscape genetics. Ecology 91(1):252-261.	Fellowship	Life sciences Ecology Technology for environmental monitoring and data analysis
Niemi, G., D. Wardrop, R. Brooks, S. Anderson, V. Brady, H. Paerl, C. Rakocinski, M. Brouwer, B. Levinson, and M. McDonald. 2004. Rationale for a new generation of indicators for coastal waters. Environ. Health Perspect. 112(9):979-986.	Grant	Ecology Innovative risk management Technology for environmental monitoring and data analysis
Paulot, F., J.D. Crounse, H.G. Kjaergaard, A. Kürten, J.M. St Clair, J.H. Seinfeld, and P.O. Wennberg. 2009. Unexpected epoxide formation in the gas-phase photooxidation of isoprene. Science 325(5941):730-733.	Grant and fellowship	Atmospheric sciences Climate sciences
Pereira, V.J., H.S. Weinberg, K.G. Linden, and P.C. Singer. 2007. UV degradation kinetics and modeling of pharmaceutical compounds in laboratory grade and surface water via direct and indirect photolysis at 254 nm. Environ. Sci. Technol. 41(5):1682-1688.	Grant	Ecology Human exposure and health effects
Peters, G.P., C.L. Weber, D. Guan, and K. Hubacek. 2007. China's growing CO_2 emissions- a race between increasing consumption and efficiency gains. Environ. Sci. Technol. 41(17):5939-5944.	Fellowship	Systems modeling and decision support Environmental economics Sustainable energy
Plevin, R.J., A.D. Jones, M.S. Torn, and H.K. Gibbs. 2010. Greenhouse gas emissions from biofuels' indirect land use change are uncertain but may be much greater than previously estimated. Environ. Sci. Technol. 44(21):8015-8021.	Fellowship	Climate sciences Sustainable energy Systems modeling and decision support Innovative risk management
Rabotyagov, S., T. Campbell, M. Jha, P.W. Gassman, J. Arnold, L. Kurkalova, S. Secchi, H. Feng, and C. L. Kling. 2010. Least-cost control of agricultural nutrient contributions to the Gulf of Mexico hypoxic zone. Ecol. Appl. 20(6):1542-1555.	Fellowship	Hydrology and water resources Environmental engineering Environmental economics Systems modeling and decision support

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Paper	STAR Funding	Scientific Domain
Reid, C.E., M.S. O'Neill, C.J. Gronlund, S.J. Brines, D.G. Brown, A.V. Diez-Roux, and J. Schwartz. Mapping community determinants of heat vulnerability. Environ. Health Perspect. 117(11):1730-1736.	Grant	Climate sciences Human exposure and health effects Risk analysis
Rhoads, K.R., E.M.L. Janssen, R.G. Luthy, and C.S. Criddle. 2008. Aerobic biotransformation and fate of N-ethyl perfluorooctane sulfonamidoethanol (N-EtFOSE) in activated sludge. Environ. Sci. Technol. 42(8):2873-2878.	Fellowship	Process technology Environmental engineering
Salzman, J., B.H. Thompson, Jr., and G.C. Daily. 2001. Protecting ecosystem services: Science, economics, and law. Stanford Environ. Law J. 20:309-332.	Grant	Ecology Environmental economics Innovative risk management
Selin, N.E., and D.J. Jacob. 2008. Seasonal and spatial patterns of mercury wet deposition in the United States: Constraints on the contribution from North American anthropogenic sources. Atmos. Environ. 42(21):5193-5204.	Fellowship	Atmospheric sciences
Shipley, H.J., S. Yean, A.T. Kan, and M.B. Tomson. 2009. Adsorption of arsenic to magnetite nanoparticles: Effect of particle concentration, pH, ionic strength, and temperature. Environ. Toxicol. Chem. 28(3):509-515.	Grant	Process technology Environmental engineering Innovative technologies
Siirila, E.R., A.K. Navarre-Sitchler, R.M. Maxwell, and J.E. McCray. 2012. A quantitative methodology to assess the risks to human health from CO_2 leakage into groundwater. Adv. Water Resour. 36:146-164.	Grant	Hydrology and water resources Risk analysis
Stone Jr., B., A.C. Mednick, T. Holloway, and S.N. Spak. 2007. Is compact growth good for air quality?. J. Am. Plan. Assoc. 73(4):404-418.	Grant	Atmospheric sciences Sustainable energy Human behavioral studies
Stow, C.A., C. Roessler, M.E. Borsuk, J.D. Bowen, and K.H. Reckhow. 2003. Comparison of estuarine water quality models for total maximum daily load development in Neuse River estuary. J. Water Resour. Plan. Manage. 129(4):307-314.	Fellowship	Hydrology and water resources Systems modeling and decision support
Tagaris, E., K. Manomaiphiboon, K.J. Liao, L.R. Leung, J.H. Woo, S. He, P. Amar, and A.G. Russell. 2007. Impacts of global climate change and emissions on regional ozone and fine particulate matter concentrations over the United States. J. Geophys. Res. Atmos. 112:D14312.	Grant	Atmospheric Sciences Climate sciences Systems Modeling and Decision Support
Tai, A.P.K., L.J. Mickley, and D.J. Jacob. 2010. Correlations between fine particulate matter (PM2.5) and meteorological variables in the United States: Implications for the sensitivity of PM2.5 to climate change. Atmos. Environ. 44(32):3976-3984.	Grant	Atmospheric sciences Climate sciences
Teisl, M.F., J. Rubin, and C.L. Noblet. 2008. Non-dirty dancing? Interactions between eco-labels and consumers. J. Econ. Psychol. 29(2):140-159.	Grant	Social sciences Environmental economics Human behavioral studies Innovative communication and participation
van Donkelaar, A., R.V. Martin, and R.J. Park. 2006. Estimating ground-level PM2. 5 using aerosol optical depth determined from satellite remote sensing. J. Geophys. Res. Atmos. 111: D21201.	Grant	Atmospheric sciences Technology for environmental monitoring and data analysis

Ward, J.R., and K.D. Lafferty. 2004. The elusive baseline of marine disease: Are diseases in ocean ecosystems increasing?. PLoS Biol. 2(4):e120.	Grant	Ecology Risk analysis
Weber, C.L., and H.S. Matthews. 2007. Embodied environmental emissions in US international trade, 1997-2004. Environ. Sci. Technol. 41(14):4875-4881.	Fellowship	Environmental economics Sustainable energy Systems modeling and decision support
Weber, C.L., and H.S. Matthews. 2008a. Food-miles and the relative climate impacts of food choices in the United States. Environ. Sci. Technol. 42(10):3508-3513.	Fellowship	Sustainable energy Systems modeling and decision support Innovative Risk Management
Weber, C.L., and H.S. Matthews. 2008b. Quantifying the global and distributional aspects of American household carbon footprint. Ecol. Econ. 66(2):379-391.	Fellowship	Climate sciences Environmental economics Sustainable energy
West, J.J., S.J. Smith, R.A. Silva, V. Naik, Y. Zhang, Z. Adelman, M.M. Fry, S. Anenberg, L.W. Horowitz, and J.F. Lamarque. 2013. Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. Nat. Clim. Change 3(10):885-889.	Grant and fellowship	Atmospheric sciences Climate sciences Human exposure and health effects Systems modeling and decision support
Yavich, A.A., K.H. Lee, K.C. Chen, L. Pape, and S.J. Masten. 2004. Evaluation of biodegradability of NOM after ozonation. Water Res. 38(12):2839-2846.	Grant	Environmental engineering Process technology
Zhang, W.X. 2003. Nanoscale iron particles for environmental remediation: An overview. J. Nanopart. Res. 5(3-4):323-332.	Grant	Hydrology and water resources Environmental engineering Innovative technologies
Zhu, X., L. Zhu, Y. Chen, and S. Tian. 2009. Acute toxicities of six manufactured nanomaterial suspensions to Daphnia magna. J. Nanopart. Res. 11(1):67-75.	Grant	Toxicology Risk analysis